

STELLAR SYSTEM GENERATOR

written and compiled by
RMF Runyan

Copyright © 2011
Concept Visions, LLC



Foreword

This generator is actually based on a system I wrote way back in 1983 before the Hubble was launched. When I found a print out of it in some old file boxes, I was shocked it had even survived. You ought to see how yellowed the paper was.

I have searched the Web for other stellar system generators. However, none were very accurate in the way a stellar system was generated. In fact, there was only one generator I found that was actually well thought out and used some actual astrophysics. [Cosmos II](#), written by Mark Peoples, is the best one I have found. For most people, Cosmos II would be good enough, even if it is written specifically for the Alternity RPG system. My current intention is to get the SSG updated as previously written.

Even with the first generator I wrote, I was striving for as best accuracy as I could achieve with my limited understanding. Time has moved on as has discoveries in astronomy. In 1983, there were no extra-solar planets discovered; only theorized. Since then, there have been over 400 planets discovered orbiting other stars (see the [Exoplanets Explorer](#), although I have not taken the time to figure out how it works). The [Doppler Spectroscopy](#) method is the most prolific planet detection method to date. Stellar system formation is one of the most viral topics in modern astronomy, evolving rapidly in several different directions. It will be some time before any definitive theory is created. Just $15\pm$ years ago, we were discovering our first definitive proof of extra-solar planets. In the next 15 to 20 years, we may be able to actually get pictures of those planets. (With today's unstable financial markets and lack of interest in astronomy and space in general, it will probably be more like 50+.)

Although this revised edition of SSG may not be entirely accurate, I did strive to be as accurate as possible. Many of the equations are simplified from some of the truly complex calculus. Even the most inaccurate equation has an error margin of only $\pm 0.037\%$. I feel that is accurate enough.

Although I have been an amateur astronomer and amateur astrophysicist for practically my whole life, do not just accept my word on everything in this document. After all, all my knowledge comes from self-studies, with no formal education into astronomy. If you feel something is wrong, then research it yourself. However, please, inform me of my inaccuracy. Simply visit this [Real Role Playing topic](#) (requires sign in/registration to post).

Dedication

This work is dedicated to my favorite science fiction authors: Isaac Asimov, Arthur C. Clarke, Robert L. Forward, Robert A. Heinlein, and Larry Niven. The best in their business.

It is also dedicated to me mom, to whom I owe a debt that can never be paid in full.

Acknowledgements

Many thanks to [NASA](#), [Jet Propulsion Laboratory](#), [Space Telescope Science Institute](#), and [HubbleSite Organization](#), of which I have borrowed much information and many of the images in this document. Also, I would like to acknowledge Mark Peoples and his Cosmos II for giving me the inspiration and desire to re-write my SSG. And Wikipedia, of which I make several references for articles. And thanks to Ray Larabie for the [Metal Lord](#) font.

Scientific Notation

Throughout this guideline, I use scientific notation using this format: 1.98892e30; where the “e(numeral)” denotes the exponent in which 10 is raised then multiplied by the decimal portion preceding the “e”. In other words, the above example would read: 1.98892×10^{30} .

Included Apps

These apps were built using Visual Basic inside Visual Studio 10. You will need to download the latest VB6 Runtime Library at:

<http://www.microsoft.com/downloads/en/details.aspx?FamilyID=7b9ba261-7a9c-43e7-9117-f673077ffb3c&DisplayLang=en>. I know Windows 7 machines already have this Runtime

Library. I think Windows Vista has it; at least mine did before installing VS10. Earlier machines I am fairly do not have it unless you have installed it.

3DPy.exe – You can use this app to calculate the distance between two points provided you know their X, Y, and Z Cartesian coordinates. If you used light years as units, you can also use this to calculate parsecs.

AtmosCalc.exe – You can use this app to create an atmospheric composition and calculate its mean molecular weight.

CelBodCalc.exe – You can use this app to calculate various parameters for a planet starting with a working volumetric mean radius, working mean density, rotational period, and land percentage.

Drake.exe – You can use this app to calculate the possible number of advanced civilizations in your galaxy. This uses the Alternative Drake Equation.

Copyright and Usage Licenses



Stellar System Generator by RMF Runyan is Copyright © 2011 by Concept Visions, LLC and licensed under a Creative Commons Attribution-NonCommercial 3.0 Unported License. All other rights reserved.

This work is licensed under the Creative Commons Attribution-NonCommercial 3.0 Unported License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc/3.0/> or send a letter to Creative Commons, 444 Castro Street, Suite 900, Mountain View, California, 94041, USA.



The included apps: SSGCalc.exe are Copyright © 2011 by Concept Visions, LLC and licensed under a Creative Commons Attribution-NoDerivs 3.0 Unported License. All other rights reserved.

This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivs 3.0 Unported License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-nd/3.0/> or send a letter to Creative Commons, 444 Castro Street, Suite 900, Mountain View, California, 94041, USA.

And a Final Note

Do not enslave yourself to the dice! In all of the steps with random tables, you may choose your result if desired. Just use some logical reasoning. Although this document is based on current astronomical knowledge, it does offer some randomness in a campaign setting. You do not need to follow this document in the order it is presented. You may skip around as desired. If there is data you do not want, skip it. You do not need to generate it. This system is intentionally designed so you may generate as little or as much data as desired.

This author believes we are unique in this universe. However, this author also believes it to be complete arrogance to assume there is no other life out there in the universe. After all, our galaxy is believed to have somewhere around 300 billion stars. As of 2008, it is estimated that there are over 100 billion galaxies in our universe. That means a possible total of 30 sextillion stars (30,000,000,000,000,000,000,000 (30 trillion billion)). Surely at *least one* of them has similar conditions to the ones here on Earth.

Besides, no matter how low the probability that any given galaxy will have intelligent life in it, the universe *must* have at least one intelligent species by definition; otherwise, the question would not arise.

“I’m sure the universe is full of intelligent life. It’s just been too intelligent to come here [Earth].”
– Arthur C. Clarke

Contents

Chapter 1: Galaxies	1	Biosphere Radii	32
Spiral and Barred-Spiral Galaxies	2	Eccentrics	33
Ring Galaxies	4	System Resources	34
Irregular Galaxies	6	Stellar Comparisons	34
Open Clusters	7	Approximate Lifetime of a Star	36
Elliptical Galaxies	8	Modified Hertzsprung-Russell	
Lenticular Galaxies	9	Diagram	36
Globular Clusters	10		
Interacting Galaxies	11	Chapter 4: Planets	45
Habitability	12	Generating Orbits	45
		Orbital Paths	45
Chapter 2: System Types	15	System with a Prime Jovian	46
Stellar Age	15	System without a Prime Jovian	48
Newborn	15	Physical Characteristics	48
Young	16	Type	48
Mature	16	Explanation of Planet Types	50
Old	17	Jovian Planets	50
Remnant	17	Terrestrial Planets	51
Solitary	17	Asteroid Belts	55
Binary	18	Mean Density	56
Trinary	19	Oblateness	56
Multiple	20	Inverse Flattening Ratio	57
Companion Stars	20	Radii	57
Unusual Objects	21	Mass	58
Nebulae	21	Volume	60
Planetary Nebula	22	Surface Gravity	60
Supernova Remnant	23	Ballistic Escape Velocity	60
Neutron Stars	23	Astronomical Albedo	61
Black Holes	24	Bond Albedo	62
		Object Flux	62
Chapter 3: Stellar Primaries	27	Land/Ocean Ratio	62
Spectral Class	27	Total Surface Area	63
The Deadly Stars	28	Land Surface Area	63
Spectral Level	29	Orbital Characteristics	63
Luminosity Class	29	Orbital Period	63
Surface Temperature	30	Orbital Eccentricity	63
Luminosity	30	Periapsis	64
Absolute Magnitude	31	Apoapsis	64
Radius	31	Orbital Inclination	65
Mass	31	Orbital Obliquity	65
Volume	31	Mean Orbital Velocity	65
Mean Density	32	Rotational Period	66
Description	32	Longitudinal Orbital Parameters	67

Longitude of Ascending Node	68
Longitude of Descending Node	69
Longitude of Periapsis	69
Longitude of Apoapsis	69
Longitude of Mean Orbital Radius	69
Atmospheric Characteristics	69
Scale Height	69
Surface Pressure	69
Surface Density	70
GAST	70
DTR	70
Wind Speeds	70
Mean Molecular Weight	71
Atmospheric Composition	71

Chapter 5: Moons	73
Generating Moons	76
Moon Orbits	77
Types of Moons and Mass	78
One-Ten Thousandth Rule	78
Rings	79

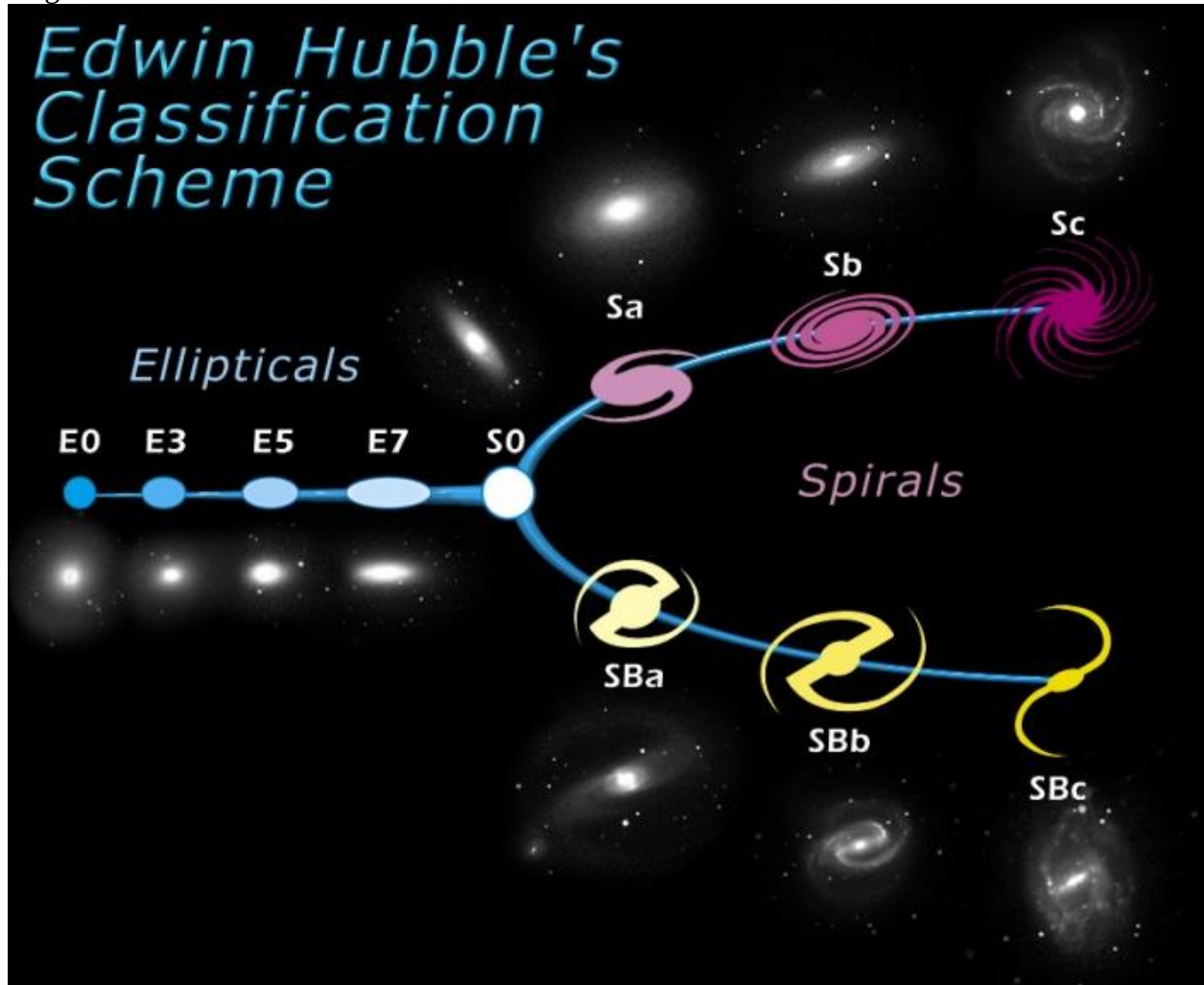
Appendices	
Apparent Magnitude	81
Angular Diameters	81
Creating Your Own Time Units	82
Standards and Measures	83
Determining Orbits Using Your World as the Foundation	
Planet	84
Transplanetary Region	84
Magnetism & Radiation	84
Geology	89
Oceanography	93
Shared Orbits	95
Binary Planets	97
Double Planets	98
Nemesis Events	99
Prime Jovians	100
Star Data Record Sheet	103
Planet Data Record Sheet	104

Chapter 1: Galaxies

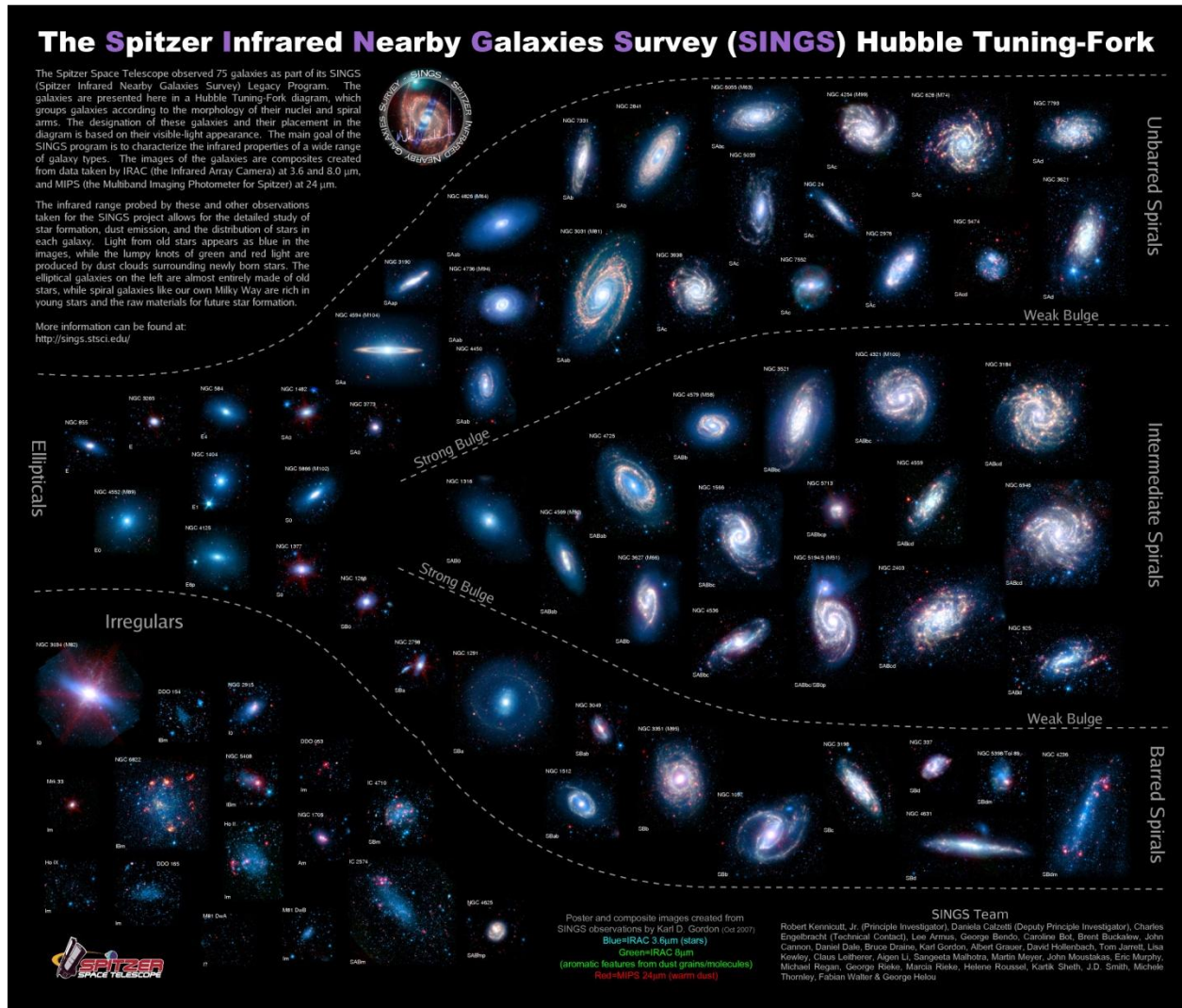
Thanks to the Hubble Telescope, we know definitively that galaxies come in many various shapes and sizes. Many of the objects we thought were planetary nebula, when seen from Earth based telescopes, have now been proven to be galaxies and interacting galaxies. In fact, it is almost impossible to view an image made with the Hubble space telescope without also seeing numerous galaxies in the background.

Most galaxies come in four basic types: spiral, barred-spiral, elliptical, and irregular. There are also globular clusters and lenticular types and the rarer ring type. Galaxies also come in three size classes: dwarf, galaxy, and giant. Virtually all galaxies fall into the [Hubble Classification Scheme](#) created by [Edwin Hubble](#) in first half of the 20th century. The original was dubbed the “tuning fork” diagram, but it has since been updated and revised. The below images show the original and updated versions.

Original Hubble Classification Scheme

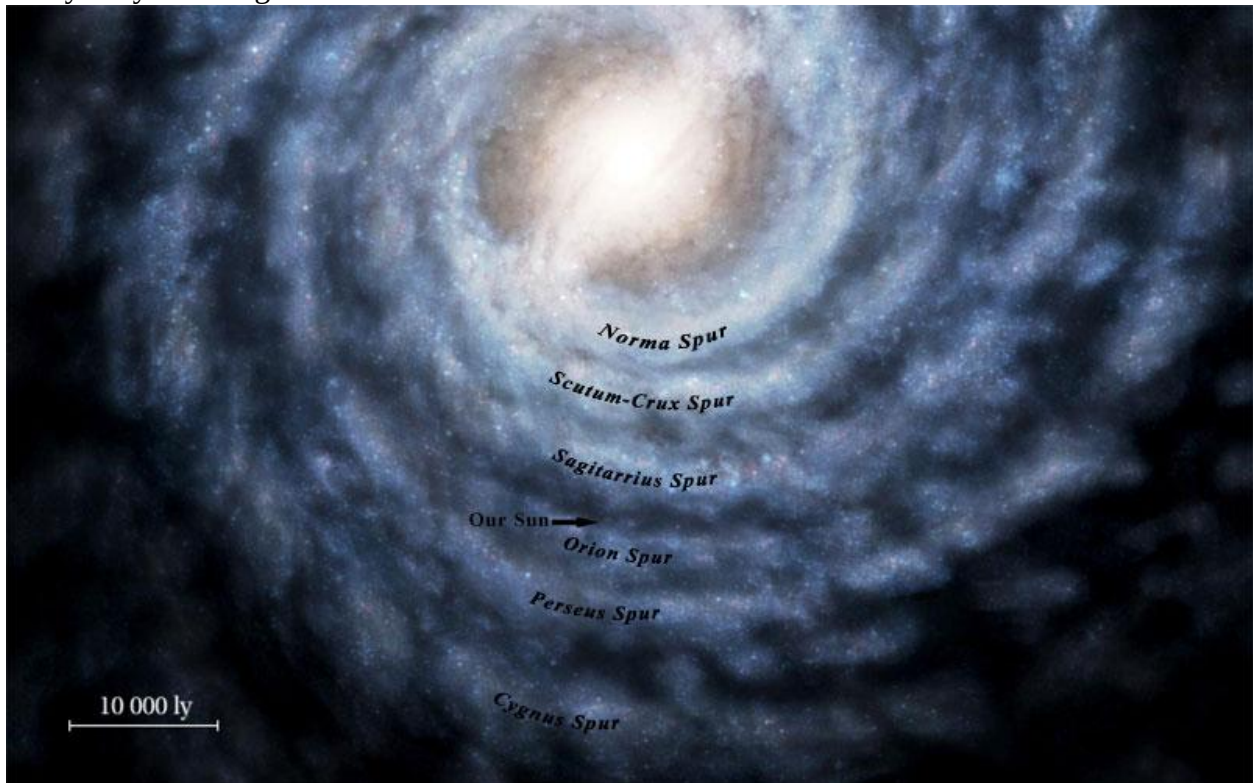


Revised Hubble Classification Scheme



the Orion Spur. The image below is a best guess layout of our Milky Way Galaxy and shows the position of our stellar system.

Milky Way Showing Our Sun Position



The images below show an assortment of spiral and barred-spiral galaxies.



NGC 2841: A “grand design” spiral.



NGC 1300: A “classic” barred-spiral.



NGC 5584: A loosely wound barred-spiral.



The "Sunny Side Up" Galaxy: An older spiral.

Ring Galaxies

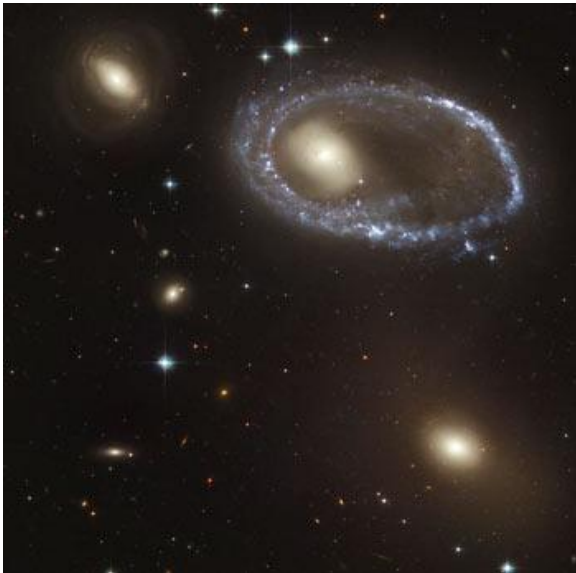
Ring galaxies were perhaps spiral or barred-spiral before colliding with another galaxy. These are the rarest of all galaxies. So far, we have only found 43 ring galaxies out of the hundreds of millions of galaxies discovered. This works out to about 1 in 13,000,000 galaxies being a ring galaxy. This type of galaxy has a structure similar to the spiral and barred-spiral galaxy; however, instead of the classic "pinwheel" structure, the ring galaxy has an elliptical core surrounded by a ring of stars. Some traces of spiral structuring may be seen between the ring and the core. Although ring galaxies have a smaller habitability zone, they may still have stellar systems that can be habitable.



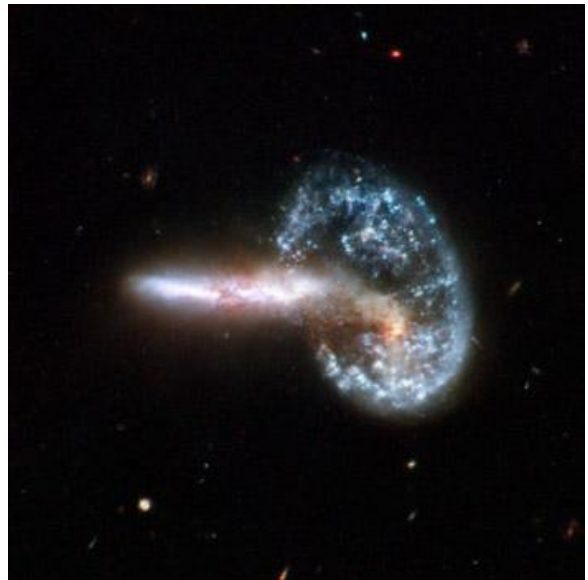
Hoag's Object: Considered the most beautiful of all ring galaxies. Notice the other ring galaxy in the far background between the ring and core near top center.



Cartwheel Galaxy: The bluish galaxy on the right is the one considered to have passed through the original spiral galaxy. The yellowish one is in the far background.



AM0644-741: An off center ring galaxy.



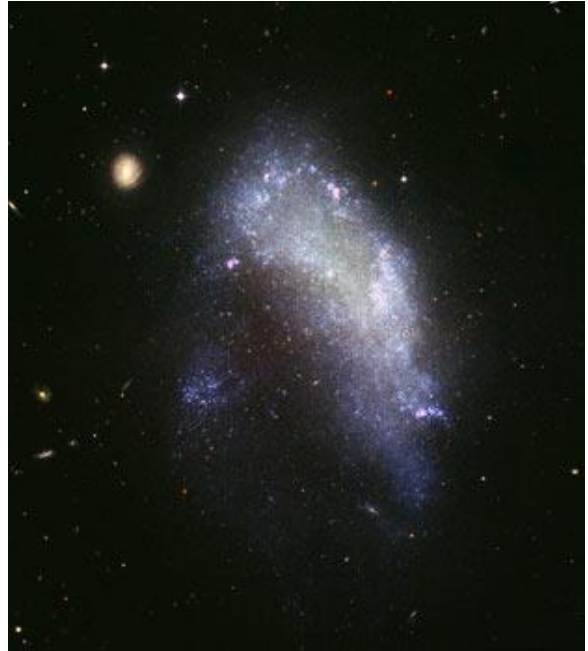
Arp 148: This is perhaps what the Cartwheel Galaxy looked like just after collision. The central streak will continue going while the remainder will become a ring galaxy.

Irregular Galaxies

Irregular galaxies are just that, rough assemblages of stars with little or no regular structure. The Large and Small Magellanic Galaxies are irregular companions of our Milky Way Galaxy. In fact, they may be remnants of collisions or close encounters with other galaxies. Irregulars tend to be too small to generate star-breeding grounds, but on occasion, they can. The [Tarantula Nebula](#) in the Large Magellanic Galaxy is a star-breeding area. Because some irregular galaxies can have star-breeding areas, there is a chance for stellar systems possessing terrestrial planets.



"Bowtie" Galaxy: This one is the result of a collision/merge of at least two galaxies.



NGC 1427-A: This one looks like it is trying to become a spiral or barred-spiral.



Polar Ring Galaxy: Notice the elliptical core is horizontal and the spiral ring is vertical.



Warped Galaxy: Although it is also a lenticular with a spiral band, this one qualifies as an irregular.

Open Clusters

Although not true galaxies, some consider open clusters to be dwarf galaxies inside other galaxies. Open clusters are actually regions within galaxies where new star formation is currently occurring or has recently occurred. They tend to have only a few tens to a few hundred stars and are rarely larger than 15 to 20 parsecs (48.925 to 65.234 light years) and rarely have any definitive structure. Open clusters are dominated by the young Population I blue-white O and B class stars and are also associated with emission and reflection nebulae (q.v.). Open clusters make poor areas for habitable terrestrial planets due to the immense radiation pumped out by the O and B stars. However, asteroid, planetesimal, and planetoid mining might be profitable, albeit dangerous.



NGC 290



NGC 3293



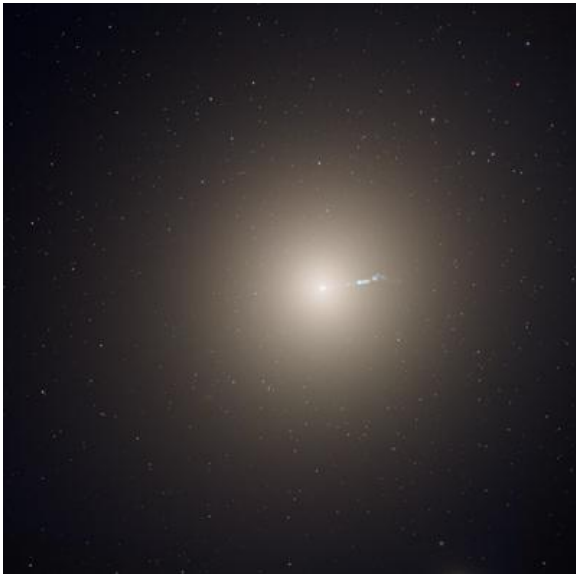
The Pleiades



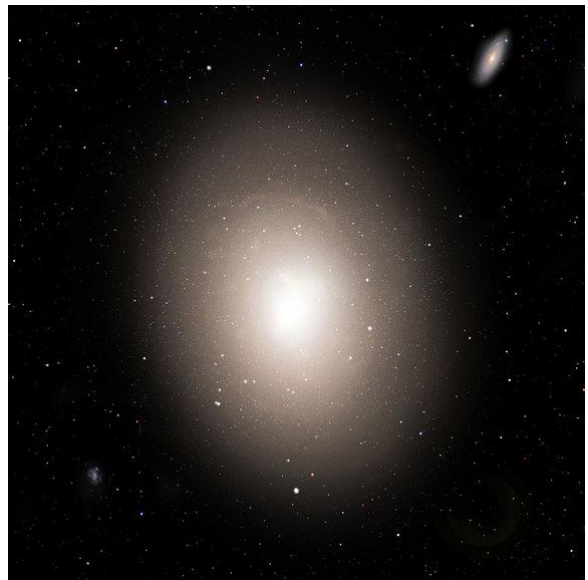
M36

Elliptical Galaxies

Also referred to as “dead” galaxies, this type of galaxy has very little gas and dust for star-breeding and are predominantly old, metallicity poor stars. Elliptical galaxies have the widest range of sizes ranging from a couple thousand light years to truly immense monsters such as M87 in the Virgo Cluster which is over 3000× the size of our Milky Way (>30,000,000 ly across). Monsters like M87 tend to sit in the centroid region of galactic superclusters. Some elliptical galaxies may possess a dusty disc which could indicate a near dying region of star-breeding. However, there will be very little new star-breeding.



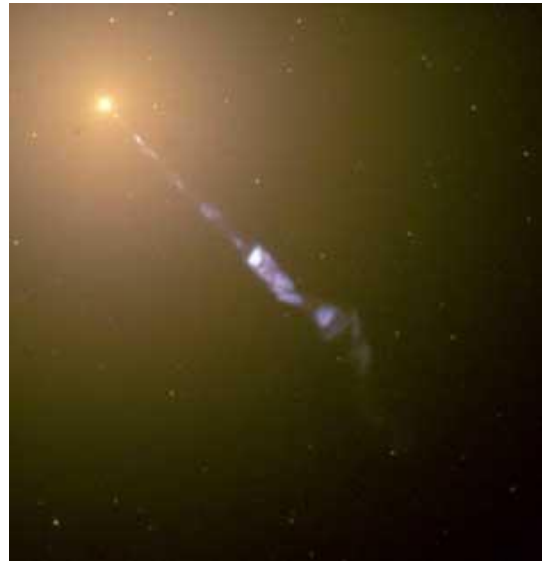
M87: The largest known galaxy. Notice the jet from the black hole on the right side.



An elliptical with some spiral banding.



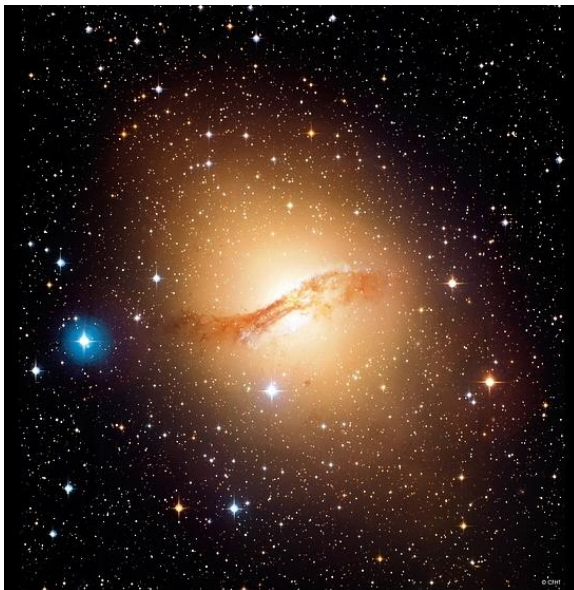
NGC 5846 & 5847: It is assumed the larger one (5846) will consume the smaller.



Close-up view of the M87 jet. Photo was made using X-ray spectrum instead of visible light.

Lenticular Galaxies

As with the elliptical galaxies, lenticulars are considered to be “dead” galaxies. They can have a spheroidal and/or barred core, but exhibit very little else in common with the spiral and barred-spiral, except for overall shape. These galaxies have used up all of their interstellar hydrogen and helium and, thus, they will have an orangish-yellow to orangish-red glow. Lenticulars also have very little in the way of star-breeding areas since they have very little gas and dust. Virtually all of the stars in a lenticular galaxy are very old, most being twice as old as our star or older.



Centauri A



NGC 2787



The “Lost” Galaxy: Although I searched, I could not find out why this one is called the “lost” galaxy. Maybe someone saw it once, and then lost where it was located?

Globular Clusters

These are very similar to open clusters, except in size and age. Globular clusters tend to be fuzzy balls of stars with an orangish-yellow to orangish-red glow. Like a lenticular galaxy, the stars tend to be old stars, most being $2\times$ or older than our sun. The stars tend to be more closely packed in the center than with open clusters. The core, which is usually one to two parsecs in size, can contain as many as one to three thousand stars. It has never been verified that any globular cluster has a black hole as most other galaxies have. Mostly there will only be Jovian planets and Pluto-like ice balls within a globular cluster.



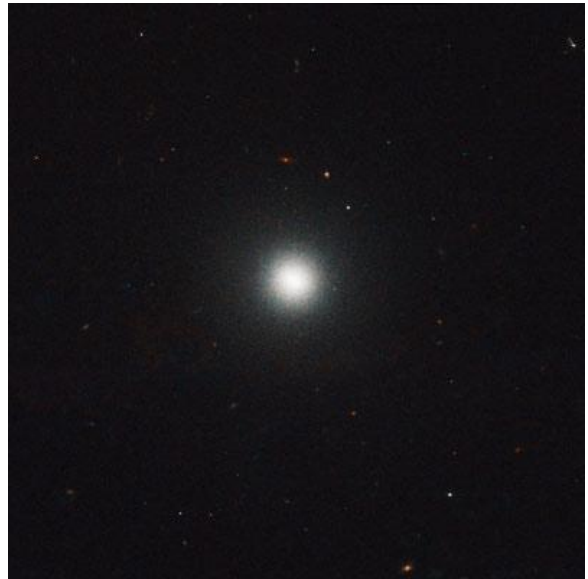
Globular Cluster 47 Tucanae from SALT



NGC 4163



Virgo Cluster Galaxy NGC 4458



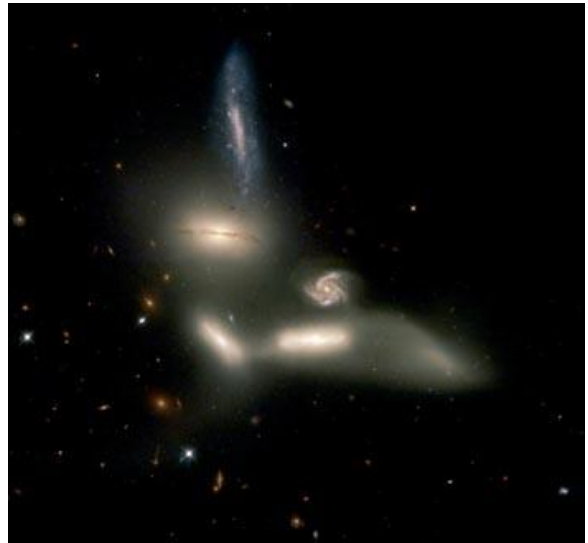
Virgo Cluster Galaxy VCC 1993

Interacting Galaxies

This is at least two galaxies, or more, that are about to collide or have just collided. Interacting galaxies tend to be hot breeding grounds for new stars, revitalizing perhaps two dead galaxies. Some of these can produce spectacular layouts.



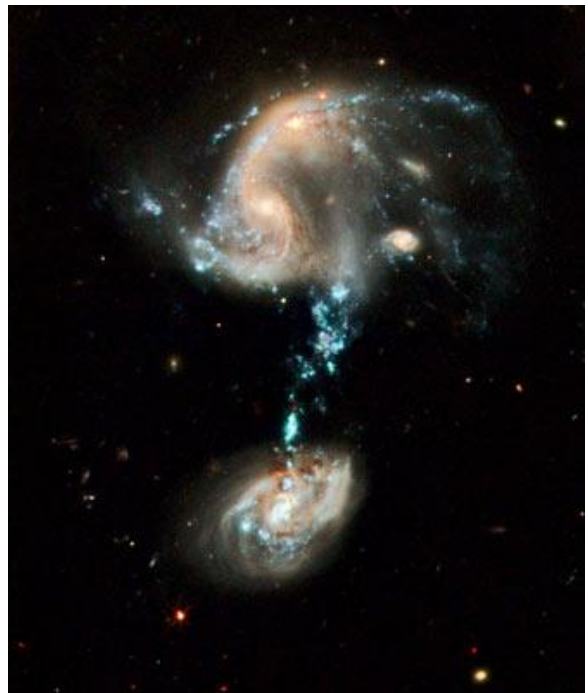
Antennae Galaxies: This name originates from it being called the Antennae Nebula due to the fact that it appeared to be a two horned nebula before the Hubble Telescope.



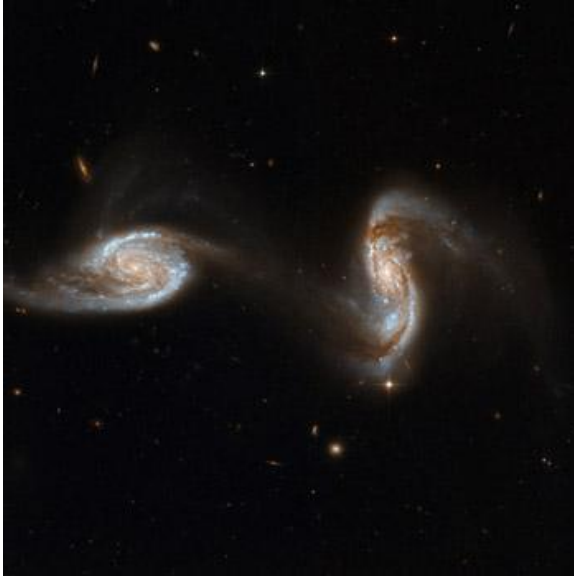
Seyfert's Sextet



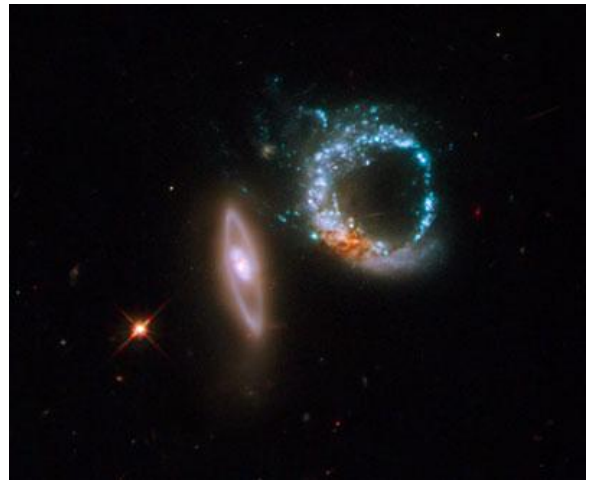
The "Rose"



Arp 194: a.k.a. The Question Mark



NGC 5257



Arp 147 scores a perfect 10

Habitability

One cannot discuss a galaxy's habitability without discussing stellar evolution. I am not going to go into explicit detail about stellar evolution because it is a subject that could literally fill a 500 page book. For further details than those discussed below, do a search on the Web for stellar evolution and star evolution. Just make sure to visit the sites that are on science organizations or universities. All others will more than likely be personal websites of persons who may or may not know what they are talking about. For a primer, visit this [Stellar Evolution](#) page at Wikipedia. It also provides two excellent links to the Department of Astronomy at the University of Maryland and Department of Astronomy at Ohio State University. Here is another nice article about [stellar evolution](#) written by [Dr. Evil Ganymede](#) (he has a doctorate in [Planetary Science](#)).

I break down stars into three types called Population I, Population II, and Population III stars. My Population type classification is not the same as the one used in true astronomy. I have simplified them for my Stellar System Generator. For the SSG, Population I stars are the Newborn and Young stars, Population II stars are the Mature stars, and Population III stars are the Old and Remnant stars.

In star-breeding areas, the first type of star to form is O and B class stars. These are referred to as Population I stars. These stars tend to be very massive and burn with very high temperatures. This causes these types of stars to live for only about 10 to 20 million years. O class stars have the shortest life, perhaps as short as 5 million years. B class stars are in the middle with a lifespan of 10 million to 1 billion years. A class stars can be classified as Population I, but they are longer lived stars, perhaps living for about 1 to 4 billion years. A class stars are on the borderline, being either Population I or Population II. At the end of their lives, these stars become very unstable and eventually destroy themselves and any planets in a supernova.

It is the remnants of these supernovae which will later create Population II stars which tend to be the A, F, G, and K stars. These are the best stars for a planetary system that can support life similar to that here on Earth. These stars live for about 4 to 15 billion years as Main Sequence stars. Towards the end of their lives, they will go through a red giant stage either burning or consuming the inner planets before they then nova, creating a planetary nebula and leaving behind a White Dwarf which will eventually cool down to a black dwarf in another estimated 15 to 25 billion years. Since the universe is only about 13.75 ± 0.25 billion years old, there are no White Dwarfs which have cooled to black dwarfs.

Population III stars are very old stars that are the M and D class stars. These stars are near the end of their lives, having burned all or almost all of their hydrogen and helium. These stars are usually not warm or luminous enough to be conducive for supporting life except for the hardest life, or the planet orbits very close to the star. However, some M class stars may have a life bearing planet.

Lenticular and globular cluster galaxies will be predominantly Population III stars. Thus, they will not be very habitable. Although elliptical galaxies may have more Population II stars, they are also mostly comprised of the older Population III stars.

Open clusters and some regions of interacting and ring galaxies will also not be very habitable due to the large number Population I stars. Since these stars are younger, they tend to pump huge amounts of radiation compared to Population II and III stars. It is due to this radiation that these regions are not very habitable.

The best galaxies for habitability are the spiral, barred-spiral, and ring galaxies. This is due to larger number of Population II stars within their boundaries.

Any galaxy can have life. Any galaxy can be habitable. Just remember that and you will not be wrong. Even a long dead globular cluster could have a G2V star with an Earth-like planet.

On a further note, the core of a galaxy will not be very hospitable for life due the proximity of the stars. A cubic parsec in the core can contain upwards of several thousand stars. This proximity from so many stars, although they may be old stars, will irradiate the region beyond the ability for normal life to exist. Also, this close proximity will not allow for any planets, most having been ejected from the galaxy core, but most likely consumed by the stars.

Chapter 2: System Types

As with galaxies, stellar systems come in various types: solitary, binary, trinary, and multiples. They also come in three broad categories: giant, major, and minor. The category is based on the primary star if it is not a solitary system. If minor systems are included, then solitary types form the greatest majority, almost 75% of all stellar systems. You should remember that multiple star systems are more massive and tend to have younger stars. It should also be noted that multiple systems of more than three stars tend to be unstable and will probably break apart in the very near future (when considering star life, this could be in 1 to 200 million years). Most multiple systems will only be binary or trinary. However there have been systems found to have as many as eight stars orbiting a common barycenter. We have not found any with more than eight stars excepting open clusters.

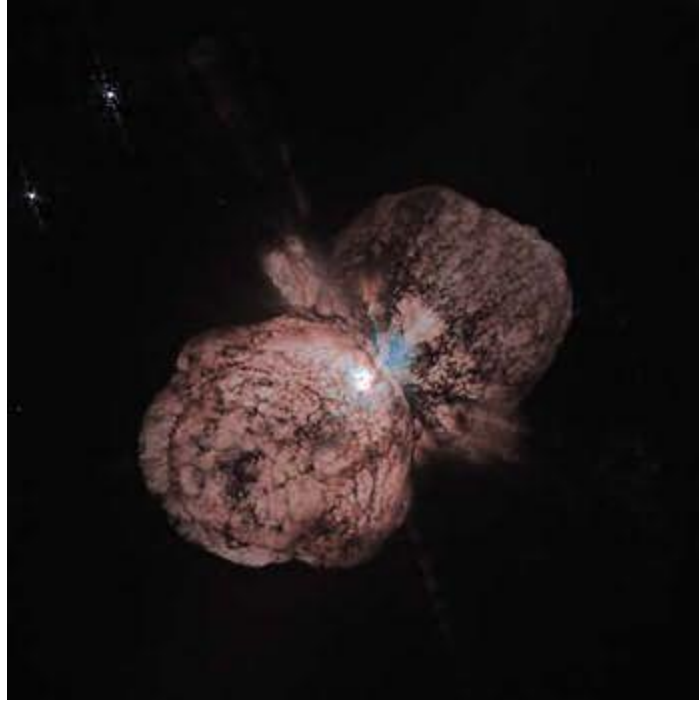
Stellar Age

Before you even consider the type of system, one should first decide the age of the system's primary. This will help to determine the classes of companion stars, if any.

Newborn

These stars are invariably O and B class stars (blue-stars), and the supergiants (O, Ia, Ib, and II luminosity class stars). O class stars and supergiants rarely live longer than 10 to 15 million years before dying in a supernova. B class stars can live for as long as 1 billion years, but usually end with a supernova also. In fact, the supernova witnessed in 2003 (I can no longer find the news report) by the Hubble telescope was from what was thought to be a stable B class star. Originally, it was thought that only the supergiants and W, O, and WO class stars were the only ones that end in supernova. Now, some scientists are beginning to think that perhaps stars as cold as the A class may be able to supernova. They are sure nothing at or below an F class can supernova since they are such long-lived and stable stars.

SSG does not generate systems for the supergiants and blue-stars since they are severely depleted of gas, it being blown out of the system by the brutal radiation these stars blast. These stars can even blow away gas and dust from neighboring systems and clouds within the star-breeding areas. These stars are also the reason for non-Jovian systems. These stars also tend to be very unstable. For our purposes, Newborn stars will usually only be surrounded by massive asteroid fields which are still trying to form into planets but are severely hampered by the immense radiation blasting outwards from these stars. Also, these stars can tend to "burp" several times before they actually go supernova. The image below shows the most recent mass ejection (burp) of the star [Eta Carinae](#) in the Carina Nebula. Eta Carinae is believed to be a WO class star. For scale, those lobes have a combined diameter greater than the size of our system (about 10 billion miles).



The Doomed Star Eta Carinae, burped about 150 years ago

Young

Young stars are less than a billion years old and are generally stable in terms of mass during this period in the star's life. Young stars are generally B and A class stars. If a B class star can live longer than 500 million years without going supernova, then it is probably stable enough to continue progressing into a normal Main Sequence lifetime. Young stars will usually still be too young to have a planetary system conducive for life. But then again, there is no reason why a young star cannot have life. Although it took $4.5 \pm$ billion years for us to evolve, there is no reason why life could not evolve faster. It seems that once the right chemicals are present for life to exist, it seems to explode with fervor. For instance, look at [Cambrian Explosion](#) of life here on Earth. Another article [here](#). If the young star is in a particularly vacuous area of the galaxy, life could evolve faster without the constant bombardment of extinction level event meteor impacts. In fact, such a system would probably have very few planets, perhaps one or two terrestrials and a prime Jovian, with the prime Jovian and star having swept away most of the other matter. Thus, in just half a billion years, a planet could have evolved rudimentary intelligent life. At least the planet could be habitable for colonization.

Mature

These are the middle-aged stars of the F, G, and K class, and some A class stars. They are usually at least 2 billion years old and can be as old as 7 billion. Planetary orbits are usually very stable during this period of a star's life and the immense impact bombardment during the newborn and young stages has practically ceased. Not to say an extinction level impact may never happen, just highly unlikely. Once a star reaches about 8 to 12 billion years old, it will go

through the red-giant stage, devouring or burning the inner planets. At the end of this red-giant stage of about 100 to 300 million years, the outer layers of the star will be expelled in a nova event as the core collapses into a white dwarf. Then the star will be a white dwarf for the next 15 to 25 billion years before cooling down to its final stage as a black dwarf (not to be confused with black hole). Any F, G, or K class star that is old is on the verge going into its red-giant stage.

Old

These are usually M class stars nearing the end of their fusion fuel reserves. Most of these stars are largely composed of heavier elements such as carbon, silicon, and iron. The M class star will rarely go nova, instead fading away into a less dense form of the black dwarf, known as the black cinder. **Note:** Black Cinder is mine own terminology.

Remnant

Not much can be said for these. They are the remains of supernova (neutron stars or black hole), nova (white dwarf), or black cinder. Although a remnant may still have planets orbiting it, none will be able to harbor life without some form of life support.

Consult the table below if you wish to determine the age of your system randomly.

Star Type	Age Determination
Supergiant	Always newborn
Class O Main Sequence	Always newborn
Class B Main Sequence	01-11 = newborn; 12-00 = young
Class A Main Sequence	01-04 = newborn; 05-98 = young; 99-00 = mature
Class F Main Sequence	01-34 = young; 35-00 = mature
Class G Main Sequence	01-08 = young; 09-97 = mature; 98-00 = old
Class K Main Sequence	01-03 = young; 04-97 = mature; -00 = old
Class M Red Dwarf	Always mature or old
Class D White Dwarf	Always remnant
Neutron Star	Always remnant

Solitary

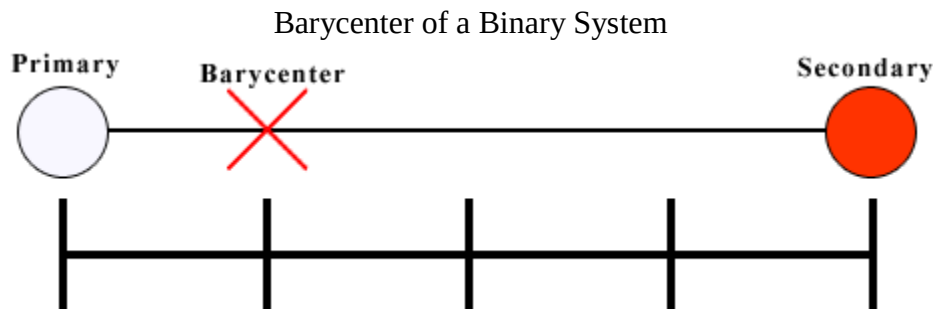
Basically, self-explanatory. This is a single star which may or may not have planets.

Binary

This is two stars which orbit around a common center of mass between the two stars. For a binary system to have habitable planets, it must be a circular system instead of an elliptical system. The elliptical form of a binary system is usually too unstable for inner planets to form close enough to also support life. In an elliptical binary system, most planets in stable orbits will be too far away to be conducive for life.

Determining the barycenter of a binary system is fairly simple. Each star of a binary system orbits at a distance proportional to its percentage of mass of the total mass of the two stars. First figure out the percentage amount of the total mass, then subtract that from 100%. This is the percentage distance of the entire distance between the two stars. Also see this [Wikipedia](#) page for some barycenter animation examples.

Example: A binary system is composed of an F class star and an M class star. The F class star has a mass of 1.5 Sol Units while the M class star has a mass of 0.5 Sol Units. The total mass is 2.0 Sol units. (Sol Unit = 1.98892×10^{30} kilograms.) The F class star has 75% of the total mass. This means the barycenter will be 25% of the total distance between the two stars. If the total distance between the two stars is 4 AUs, this means the barycenter is 1 AU from the F class star and 3 AUs from the M class star. See the image below for visual representation.



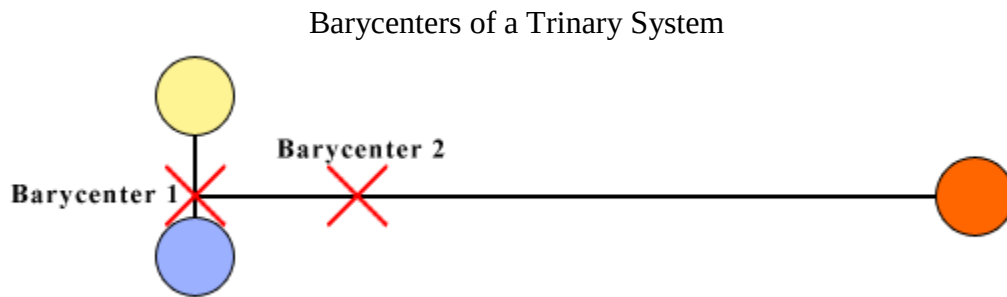
Binary Star Separation

Roll	Result
01-09	2d8 million kilometer separation. Roll d100 again, on a 96+, the system is a contact system binary with a separation $\leq$ one stellar diameter. The stars share their stellar atmosphere. This creates brutally intense radiation and particle winds rendering the system inhospitable to life. Shielded bases may exist though.
10-18	$d12 \div 10$ AU separation.
19-36	$d20$ AU separation.
37-64	$2d6 \times 10$ AU separation.
65-82	$d12 \times 100$ AU separation.
83-91	$d12 \times 1000$ AU separation.
92-00	$d6 \times 10,000$ AU separation.

Trinary

Trinary systems are usually a binary system orbiting with another solitary. For some nice, simple animations (up to quaternary systems), see this page [@atlasoftheuniverse.com](http://atlasoftheuniverse.com).

Determining the barycenter of a trinary system is a two step process. First, the two most massive stars will be orbiting each other like in a binary system. Once you find this barycenter, treat the two stars as if a single star to determine the barycenter with the third star. See the image below for visual representation.



Trinary and Quaternary Separation Sub-Pair Separation

Roll	Result
01-14	2d8 million kilometer separation. Roll d100 again, on a 96+, the system is a contact system binary with a separation $\leq$ one stellar diameter. The stars share their stellar atmosphere. This creates brutally intense radiation and particle winds rendering the system inhospitable to life. In fact, this may cause the third star to be “pushed” out of the system unless the orbit is stable. Shielded bases may exist though.
15-29	d12/10 AU separation
29-58	d20 AU separation
59-00	2d6 $\times$ 10 AU separation

Secondary Separation in Trinary/Quaternary System

Roll	Result
01-50	d12 $\times$ 100 AU separation
51-83	d12 $\times$ 1000 AU separation
84-00	d6 $\times$ 10,000 AU separation

Multiple

Quaternary systems are usually a double binary system. You will have to calculate the barycenter for the two individual binaries, and then calculate the third barycenter for these two binaries. I would suggest not having any system greater than a trinary due to the complexity of having to calculate multiple barycenters for quinary, senary, septenary, and octonary systems. Besides, any system with more than three stars will probably pump out so much radiation as to have planets that are nothing more than burnt cinders. Or, they would have to be too far away to be nothing more than a large ice-ball, or Jovian type planets.

Companion Stars

First, look in Chapter 3: Stellar Primaries >> Spectral Class, Spectral Level, and Luminosity Class, and determine these parameters for the primary star. This will determine the maximum class for the companion stars. Supergiant Systems below refers to Spectral Class O stars and Luminosity Class 0, Ia, Ib, II, and III stars. Major Systems below refers to Spectral B, A, F, G, and K stars and Luminosity Class IV and V stars. Minor Systems is all others.

Supergiant System		Major System		Minor System	
01-20	Solitary	01-50	Solitary	01-75	Solitary
21-50	Binary	51-85	Binary	76-95	Binary
51-75	Trinary	86-97	Trinary	96-00	Trinary
76-95	Quaternary	98-00	Quaternary		
96-00	Quinary +; roll d4+4 for number				

Modifiers for Companion Stars

Spectral Class Modifiers			Luminosity Class Modifiers	
Spectral Class	Hottest Companion Class Allowable	Modifier to Spectral Class Roll	Luminosity Class	Modifier to Luminosity Class Roll
O	O	+0	Hypergiant (0)	+1
B	B	+0	Luminous Supergiant (Ia)	+2
A	A	+1	Supergiant (Ib)	+3
F	F	+4	Bright Giant (II)	+5
G	G	+12	Giant (III)	+10
K	K	+24	Subgiant (IV)	+20
M	M	+24	Main Sequence (V)	+30
			Dwarf (VI)	+90

Once you determine the primary's companion, use the secondary star to determine the modifiers for the tertiary star, and then use the tertiary to determine the quaternary star, and so on, until you have determined all the stars.

Unusual Objects

Many unusual objects exist out there in the universe. If you are an adherent to hard science, these include black holes, black dwarfs, planetary nebula, supernova remnants, neutron stars, quasars. But if you like pseudo-science, these can include temporal rifts, quantum singularity, dimensional rift, cosmic string, quantum filament, wormhole, transwarp conduit, gravimetric expulsor (opposite of a black hole), etc. In the SSG, I stick with the hard science objects. For the pseudo-science objects, you are on your own. Although I did come up with the idea “gravimetric expulsor,” I have never expounded on it.

Nebulae

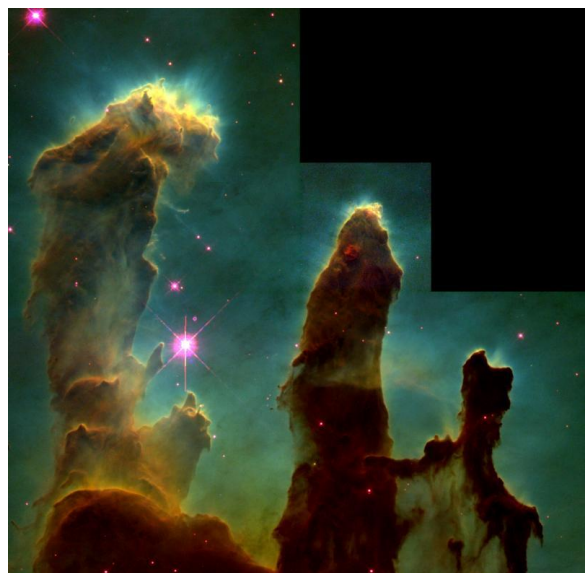
Nebulae come in three different types: emission, reflection, and dark. Emission nebulae are nebula which have a star or stars inside and are often newly formed stars. These stars excite the nebula dust and gas with the emission of their UV radiation. This is the same way that neon arc tubes work. Although they appear very colorful in Hubble photos, this is due to the very long exposure times taken in varying spectrums (red, green, blue, NIR, X-ray, etc.) and then combined. To our naked eyes, they would actually appear to be milky and colorless.

Reflection and dark nebula are virtually the same. The only difference depends upon the locations of any nearby stars, the nebula, and the observer. If the nebula is between the star and observer, then it is a dark nebula. If the star is between the nebula and observer, then it is a reflection nebula.

Although nebula can be quite large, spanning an average of 30 to 35 parsecs (97.85 to 114.16 light years), the concentration of dust and gas is still sparse enough to allow astrogation in safety. However, there can be pockets that are dense enough to present hazards to astrogation.



“Mystic Mountain” in Carina Nebula



“Pillars of Creation” in Eagle Nebula

Planetary Nebulae

These nebulae have nothing to do with planets and are not even nebula, despite their name. These are actually the outer layers of a main sequence star that has gone nova after going through its red-giant stage. These layers expand outward from the star like an enlarging bubble. They will also tend to glow like an emission nebula since the star's core, now a white dwarf, continues to shine. Planetary nebula are not much denser than the vacuum of space thus, do not present any particular hazard to space travel. Planetary nebulae rarely get larger than a half parsec and only last for a few tens of thousands of years.



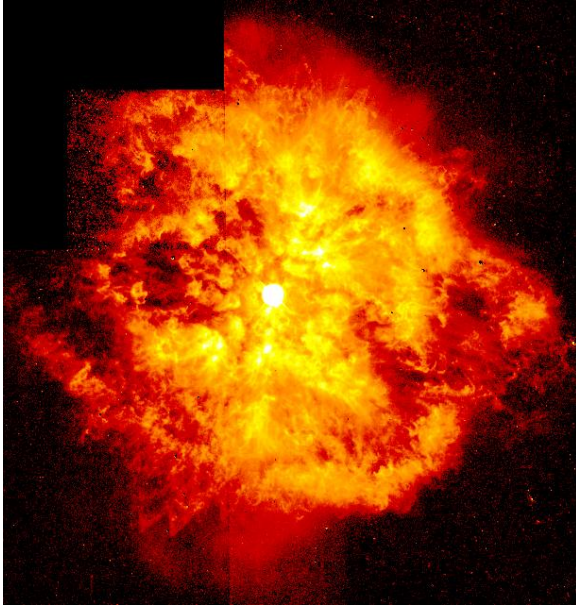
“Eskimo” Nebula



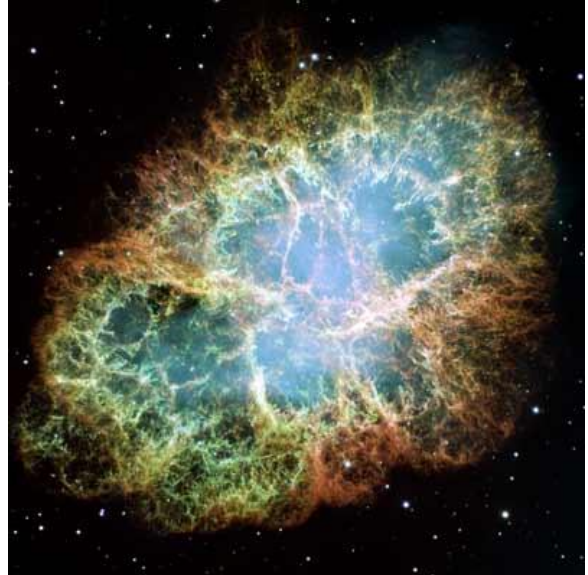
“Glowing Eye” Nebula, sometimes called “The Eye of God”

Supernova Remnant

While similar in mechanics as planetary nebula, they are blown outward at a much greater velocity. These can be up to two parsecs in size and, like planetary nebulae, also last for only a few tens of thousands of years.



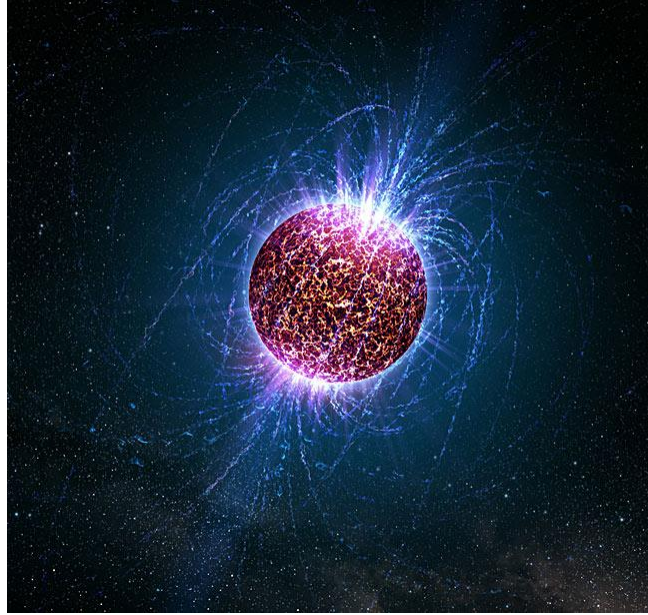
Supernova Remnant at star WR124



The most famous supernova remnant:
Crab Nebula (in 1054 AD)

Neutron Stars

These are the remaining core of a star that has gone supernova. In a supernova, the star's core collapses suddenly, in a matter of a few minutes, and ignites the fuel that appears in between the outer layer and core. This explosion is tremendously powerful both blasting the outer layers away and further imploding the collapse of the core. Unlike main sequence stars that nova and become white dwarfs, these are from O, B, and possibly A spectral class stars and the supergiants. With a much greater mass, the core of these stars will continue to collapse beyond the white dwarf star into a degenerate mass composed of neutrons and quarks. The rebound effect of this collapse causes the explosion to be much greater than the explosion itself. It is theorized that this blast can propel the matter of the outer layers at velocities approaching 75% to 85% the speed of light. The remaining neutron star will rotate several times a second, some as much as a few thousand times a second. Neutron stars will possess immense magnetic fields, often in excess of a million gauss. Magnetic fields this powerful are strong enough to actually distort the shape of atoms and pull molecules apart into what is called a "magnetic soup." A neutron star is so dense that one teaspoon (5 milliliters) of its material would have a mass over 5.5×10^{12} kg, about 900 times the mass of the Great Pyramid of Giza ([Wikipedia](#)). Neutron stars also emit powerful radio beacons from their magnetic poles and are seen as "pulsars" from Earth.

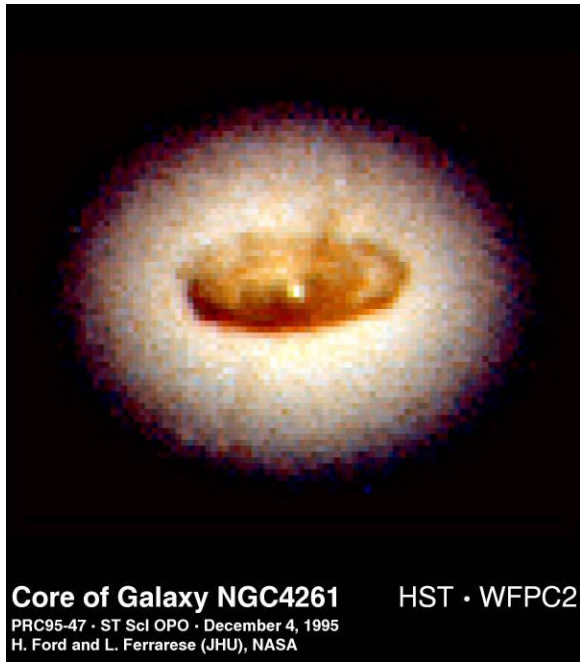


Artist's Concept of a neutron star
with visible magnetic streamers

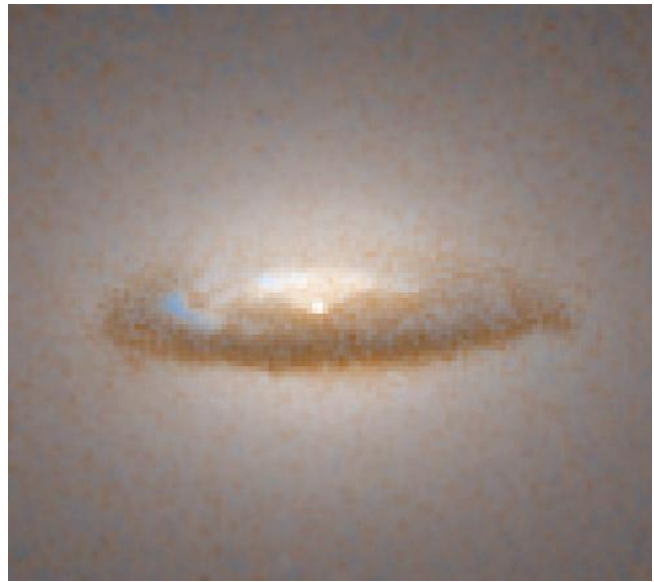
Black Holes

Sometimes a star is so massive that when it goes through the supernova stage, the core actually never stops collapsing and becomes a singularity, or black hole. There are only two ways for a black hole to be visible. As it moves across a starry background, its warping effect can be seen as it distorts the light around the event horizon. The other way is for the black hole to have a huge fuel source that is falling into the event horizon, creating an accretion disk. Without an accretion disk and adequate background light sources, the only way to detect a black hole is by its extremely powerful gravimetric attraction. If one has no way to detect gravimetric fields, distortion of background light sources, or an accretion disk, then the only way to detect a black hole is by colliding with it. And I do not think I need to detail those results.

There is a current proposal to change the name of black holes to [MECO](#): *magnetospheric eternally collapsing object*. However, I prefer the term “black hole,” or “singularity.”



First of the possible black holes



Core of NGC 7052

Here is a nice 18m 48s video about the “Largest Black Holes in the Universe” [@YouTube](#). You will have to tolerate ads... However, you can click past them (I think, I could).

Chapter 3: Stellar Primaries

Now that you have decided on the type of galaxy and system, it is time to determine what kind of stellar primary you will have. First, we will need to look into the different types of stars there are.

For the purposes of this SSG, I have grouped stars into three broad category types: giants, major, and minor. I do not include dwarfs or minors because they are usually poor stars for harboring life. Of course, dwarf stars may have life, but the rarity is great enough that I chose to not include them. If you want a dwarf star to have life, then do so. You can still use this SSG to generate the data.

The Stellar Type of a star comprises three elements: Spectral Class, Spectral Level, and Luminosity Class. For an example, our star, Sol, is a G2V Stellar Type. The "G" is the Spectral Class, "2" is the Spectral Level, and "V" is the Luminosity Class. Here is an interactive Hertzsprung-Russell Diagram [@University of Nebraska at Lincoln](#).

Spectral Class

There are seven main Spectral Classes: O, B, A, F, G, K, and M. A nice mnemonic: **Oh Be A Fine Girl/Guy Kiss Me**. And, 3 colder and less massive “brown dwarf” classes: L, T, Y. There are also 8 additional spectral subclasses: C, D, N, P, Q, R, S, W. Then, there are a number of “slash” class stars. Also see this [Wikipedia](#) article for further discussion, external links, and web portals. The major problem with this Wikipedia page, and I have been contacting Wikipedia about it, is that the temperature ranges for the spectral classes are wrong. At least when compared to the temperature ranges I have seen all my life and as listed in the astronomy books I have and keep (expensive) updated versions. This webpage at [search.com](#) has the correct temperature ranges. At least the temperature ranges I have been familiar with all my life. Use the below tables to determine a star randomly. Or, just simply choose. The best stars for Earth-like planets are the F, G, and K class stars.

Table 1: Spectral Class	
Roll	Result
01	Special; roll Table 2
02-04	F
05-12	G
13-24	K
25-00	M

Table 2: Spectral Class Specials	
Roll	Result

01-40	reroll Table 1
41-75	A
76-90	B
91	O
92-93	L
94-95	T
96	Y
97	White Dwarf
98	Neutron Star
99	Black Hole
00	Special

Specials from table 2 are reserved for those who wish to come up with a pseudo-science object such as gravimetric expulsor, cosmic string, temporal rift, interspatial flexor, etc. This SSG does not cover any of these types of objects.

The Deadly Stars

This is a discussion specifically within the Main Sequence stars (Luminosity Class V).

Spectral O and B Class stars are most likely to not have habitable planets. Not to say that they cannot have them, just very unlikely. O class stars range from 16 to 60 times the mass of our sun and 6.5 to 15 times the radius. B class stars range from 2.1 to 18 times the mass and 1.8 to 6.5 times the radius. The image below shows the *relative mean* sizes of Luminosity Class V stars.

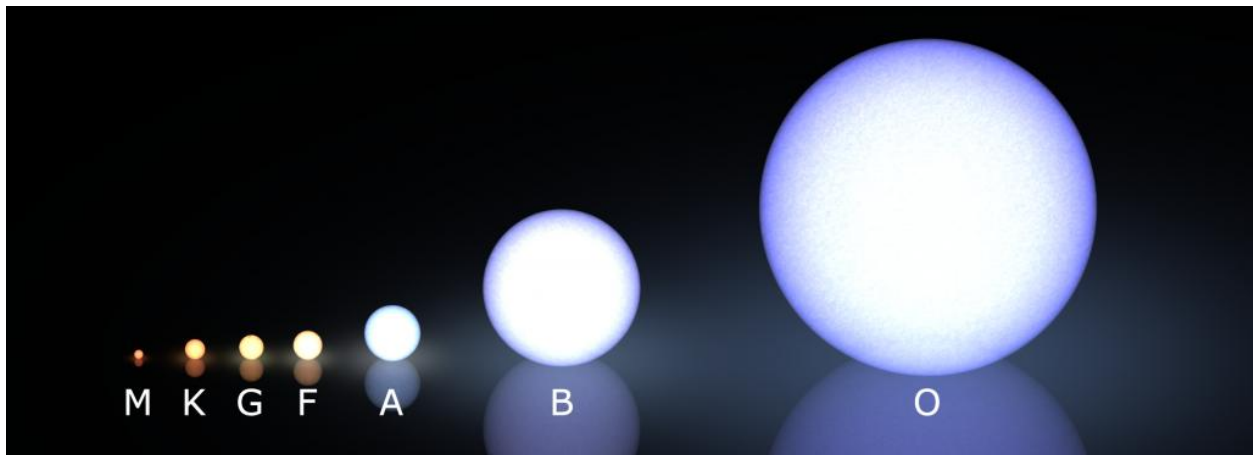


Image borrowed from [Young Astronomers](#)

Although they could have stellar systems, class O and B stars are so massive that they will have pulled all of the stellar material into themselves and left almost nothing for planets to form, except perhaps the lower end mass B stars. And what little bit may have remained would have been blown away by the star's immense radiation and particle winds. Another main problem with these stars that may have terrestrial planets is the immense amount of radiation they pump out. Any terrestrial planet would have to have a density so great in order to have an atmosphere

thick enough to block the star's radiation that the planet would end up being a radioactive fireball (vesuvian or furian, q.v.). Of course, the planet could have a life form that relies on the radiation, but the planet surely would not be amicable for life as we understand it. More than likely, it would be a mineral-based life form. Protoplasmic, carbon-based life forms surely could not survive in such a radioactively hostile world. Or the planet would have to be far enough away from the star that it would be an arctic wasteland, supporting only the most primitive of life forms.

Spectral class A stars can have terrestrial planets that can be Earth-like. However, they are very rare. Currently, of all the stars we have catalogued, more than 99% of all stars are F, G, K, and M class stars. And this is including **ALL** Luminosity Classes. Thus, all A+ spectral class stars are on Table 2 above.

Spectral Level

Depicted by a number from 0 to 9 indicating tenths of the range between two star classes, so that A5 is five-tenths between A0 and F0, but A2 is two-tenths of the full range from A0 to F0. Another way of looking at this number is the number indicates the number of tenths away from the 0 end of the scale. Thus, the A2 would be two-tenths away from being A0. Lower numbered stars in the same class are hotter. This number also helps to determine the temperature of the star. For random determination, simply roll a d10, reading a 0 as zero.

Luminosity Class

Since the radius and mass of a star is proportional to luminosity, determining the luminosity class will later aid in determining the star's radius and mass. As always, you may either use the below table, or simply choose.

Roll	Class	Description
01	0	Hypergiant
02	Ia	Luminous Supergiant
03	Ib	Supergiant
04-05	II	Bright Giant
06-10	III	Giant
11-20	IV	Subgiant
21-90	V	Main Sequence
91-97	VI	Dwarf
98-00	VII	White Dwarf/Neutron Star

NOTE: If you roll a subgiant (Luminosity Class IV) for an O, K, or M class star, simply reroll. There are no O, K, or M class subgiants. Reason is still unknown. However, if you want a Subgiant O, K, or M class star, go for it. I have never seen any reason why there cannot be one.

Surface Temperature

Knowing the star's surface temperature will help in determining the star's luminosity and some other parameters.

Temperature Ranges				
Spectral Class	Temperature (°K)			
	Minimum	Maximum	Difference	Mean
O	30,000	60,000	30,000	45,000
B	10,000	30,000	20,000	20,000
A	7500	10,000	2500	8750
F	6000	7500	1500	6750
G	5000	6000	1000	5500
K	3500	5000	1500	4250
M	2000	3500	1500	2750

- 1) Roll d100, closed, reading "00" as 00, to get a number 00-99. This is referred to as Temperature Rating.
- 2) Concatenate result of Step 1 with the Spectral Level to get a number ranging from 000 to 999. Remember, the higher this number, the lower the temperature.
- 3) Subtract result of Step 2 from 1000.
- 4) Divide result of Step 3 by 1000.
- 5) Multiply result of Step 4 by Difference in above table.
- 6) Add result of Step 5 to Minimum in above table.
- 7) This is the surface temperature in degrees Kelvin (°K).
- 8) Divide result of Step 7 by 5778 to get Temperature Factor.

Conversions

- °C = °K - 273.15
- °F = ((°K - 273.15) × 1.8) + 32
- °R = °K × 1.8

Luminosity

Luminosity is the measure of a star's energy output. This may be listed in Watts/second, but this is incorrect. Luminosity is always measured in Joules. Although 1 W/s = 1 J, the difference is power and energy. See this webpage [@stardestroyer.net](http://stardestroyer.net) (look for header "Force, Energy, and Power") for an excellent discussion on the difference.

$$L = \sigma T^4 (4\pi r^2)$$

Where **L** = luminosity in Joules (÷ 3.839e26 for Sol units); **σ** = Stefan-Boltzmann Constant (5.6704e-8 W/m²°K⁴); **T** = surface temperature in degrees Kelvin; **r** = volumetric mean radius in meters.

Absolute Magnitude

This is the measure of a star's brightness at a distance of 10 parsecs (32.61688071 light years). Also see this [Wikipedia](#) page for further information.

$$M = 4.83 - 2.5 \log L$$

Where **M** = absolute magnitude; **L** = luminosity in Sol units.

Radius

This is the size of the star. Since stars tend to vary greatly in their shape from rotation period to rotation period, this is the volumetric mean radius.

$$R = \sqrt{\frac{L}{4\pi\sigma T^4}}$$

Where **R** = volumetric mean radius in meters ($\div 6.955\text{e}8$ for Sol units); **L** = luminosity in joules; σ = Stefan-Boltzmann Constant ($5.6704\text{e-}8 \text{ W/m}^2\text{K}^4$); **T** = surface temperature in degrees Kelvin.

Mass

This is the mass of the star. Need I say more? Most often, it is measured in kilograms.

$$M = L^{\frac{1}{3.5}}$$

Where **M** = mass in Sol units ($\times 1.98892\text{e}30$ kilograms); **L** = luminosity in Sol units.

Volume

This is the star's volume. Volume units are dependent upon units used for radius. If radius units are kilometers, then volume will be cubic kilometers. Meters would equal cubic meters. Etc.

$$V = \frac{4\pi r^3}{3}$$

Where **V** = volume; **r** = volumetric mean radius.

Mean Density

This is the mean density of the star. Note that is the overall mean density. Density in stars, as with planets, will vary from layer to layer as one works towards the inner core. Also note that density units will be dependent upon units used for mass and volume. Example: If mass uses kilograms and volume uses cubic meters (this is the standard), then density will be in kilograms/meter³.

$$D = \frac{M}{V}$$

Where **D** = mean density; **M** = mass; **V** = volume.

Description

This is the apparent color of the star. Main color is highlighted in *green italics*, with adjectives following.

Spectral Class	Description
O	<i>extremely bright blue</i> (very blinding)
B	<i>very bright blue-white</i> (blinding); from blue (hottest) to whitish (coolest)
A	<i>white</i> (fairly blinding); from bluish (hottest) to white (coolest)
F	<i>yellow-white</i> ; from whitish (hottest) to yellowish (coolest)
G	<i>yellow</i> ; from whitish (hottest) to orangish (coolest)
K	<i>orange</i> ; from yellowish (hottest) to reddish (coolest)
M	<i>red</i> ; from orangish (hottest) to dim (coolest)

Here is a [link](#) about the apparent color of a star. And Mitchell N. Charity's [home page](#).

Biosphere Radii

This is the “magic zone” for planets to be conducive for life. It is also referred to as the Goldilocks Zone, Comfort Zone, and Habitability Zone. I chose Biosphere Radii since this region is determined by the innermost radius and outermost radius. If not recorded, then convert the star's luminosity into Sol units by dividing luminosity by 3.839e26. Take the square root of this number then multiply by 0.7 and 3.0. Results are the innermost and outermost biosphere radii in AUs. To convert AUs to meters, multiply by 149,597,870,691. Most often, only two planets will fit in this region.

$$\begin{aligned} Ei &= 0.7\sqrt{L} \\ Eo &= 3.0\sqrt{L} \end{aligned}$$

Where **Ei** = innermost radius; **Eo** = outermost radius; **L** = luminosity in Sol units.

Eccentrics

Eccentrics are captured planets, rogue comets, or other stellar objects that did not form in the initial protoplanetary disk of the stellar system. These objects are exceptionally hazardous since they usually orbit the stellar primary in orbits out of the ecliptic, but within the orbit of the furthest orbital path.

Eccentric Determination: Convert the star's mass into Sol units by dividing its mass by 1.98892×10^{30} , round off. This is the Mass Factor.

First Roll: Roll d100, closed. Add the Mass Factor and +30. If 101+, then there is at least one eccentricity. Go to Second Roll.

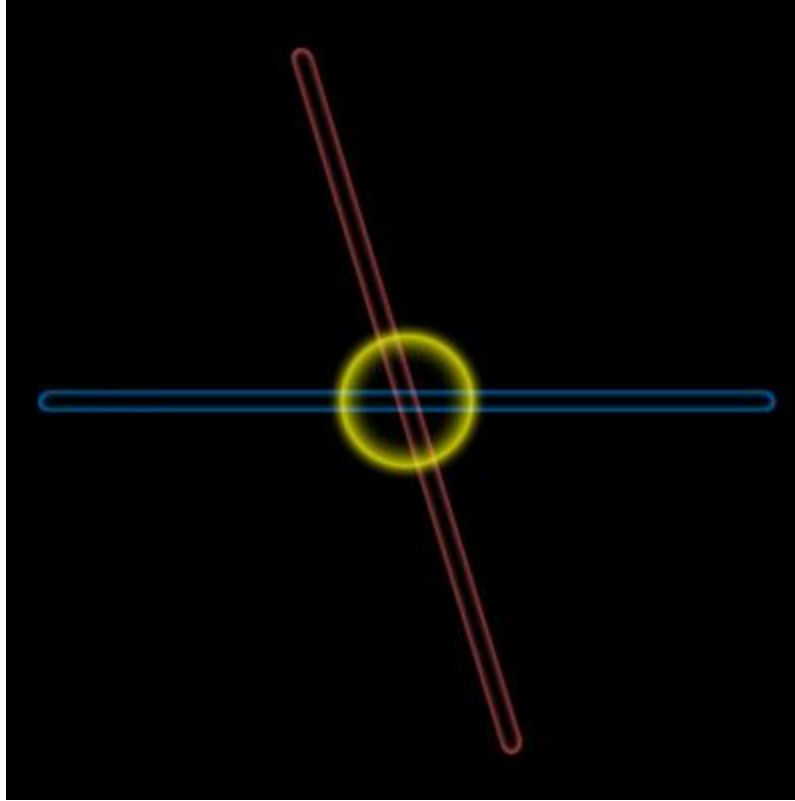
Second Roll: Roll d100, closed. Add Mass Factor $\times 0.5$ and +20. If 101+, then there is a second eccentricity. Go to Third Roll.

Third Roll: Roll d100, closed. Add Mass Factor $\times 0.25$ and +10. If 101+, then there is a third eccentricity. Go to Fourth Roll.

Fourth Roll: Roll d100, closed. Add Mass Factor $\times 0.125$ and +0. If 101+, then there is a fourth eccentricity.

Remember, this SSG only determines the major Eccentrics, as shown above. There may be other Eccentrics. If desired, repeat this method to determine other minor Eccentrics. And keep repeating for further eccentrics. However, remember this: The more Eccentrics there are, the less likely a planet may be conducive for complex life, meaning there would be a greater possibility of more extinction level event impacts. Either choose the orbital paths of the eccentrics or determine them randomly, the choice is yours. Eccentrics can be the same orbital paths determined above or can be extra ones. For instance, you may choose that orbit 4 has the focus planet on the ecliptic but also has an eccentric with the same orbital radius but has an orbital inclination of -73° . See image below for a visual representation. Of course, an eccentric as shown in the below image can cause another cataclysmic event known as orbital perturbation. In other words, the two objects can come close to colliding, but instead perturb each other out of their orbits. Such a perturbation can cause the two objects to never come close to colliding ever again, but the perturbation can cause cataclysmic effects such as completely changing the orbital radius and thus the global climate.

If you really think about it, you just might decide to eliminate all eccentrics. In fact, if desired, you can just skip this step. Remember, I said to not be a slave to the dice. Only, if you want eccentrics do you need to place them. Most often, I just skip this step. This is mainly due to the fact that I do not want to have to go through the brutal mathematics for recalculating any major orbital perturbations. Also remember that perturbing even one orbit will also perturb all others in the system. Reiteration: The mathematics are brutal. Although there are computer programs that will do this for you, there are very few laymen out there who could even understand how to use those programs.



Blue orbit is the focus planet. Red is the eccentric.
Yellow circle is the primary (star). Of course, scale is exaggerated.

For the orbital inclination, either choose, or roll 1d100, open-ended. The result of the roll is the orbital inclination in degrees off the ecliptic.

Also, eccentrics will also tend to have more elliptical orbits. In the above image, both orbits have the same radius. However, even an eccentric with an elliptical orbit could still intersect a planet's orbit at one or two points. And this could lead to a situation similar to the Threadfalls in *Dragonriders of Pern*.

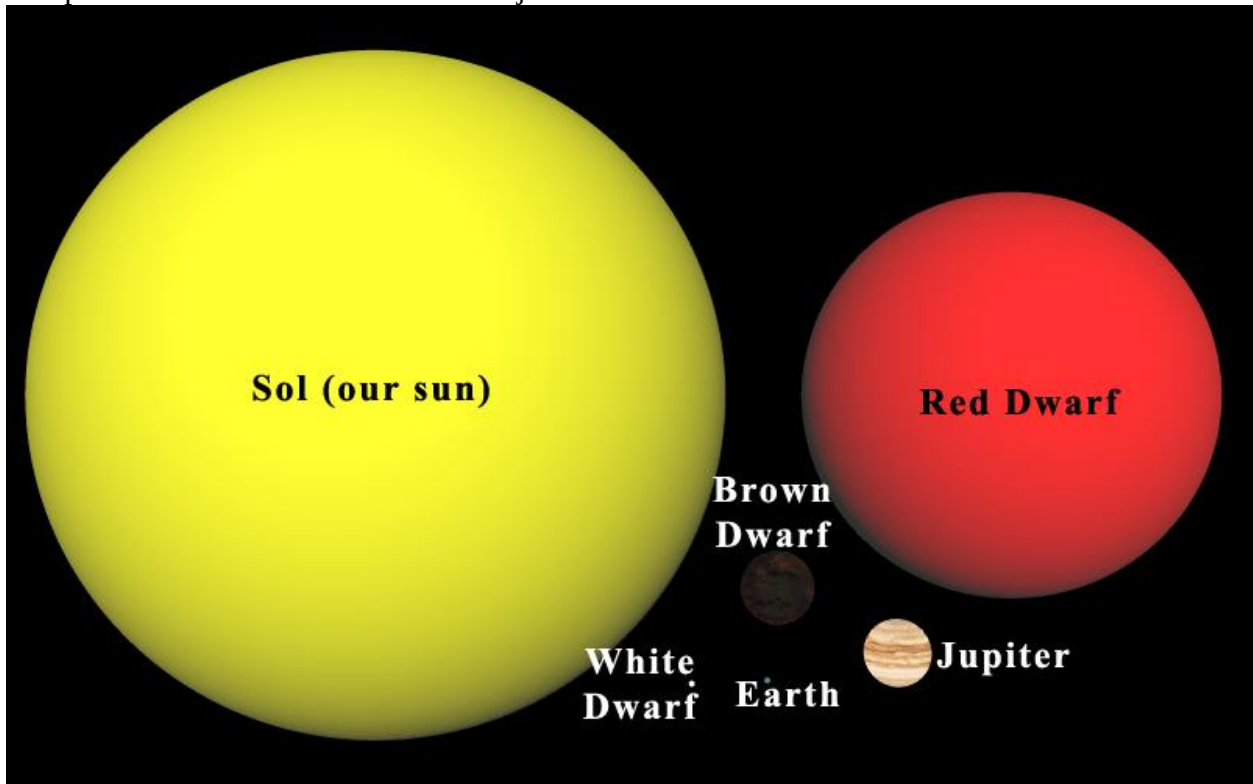
System Resources

This is usually listed as adjectives such as extremely poor, very rich, exceptional, etc. This is usually determined after all the planets and moons have been generated. The greater the overall density within the system is, the greater the resources.

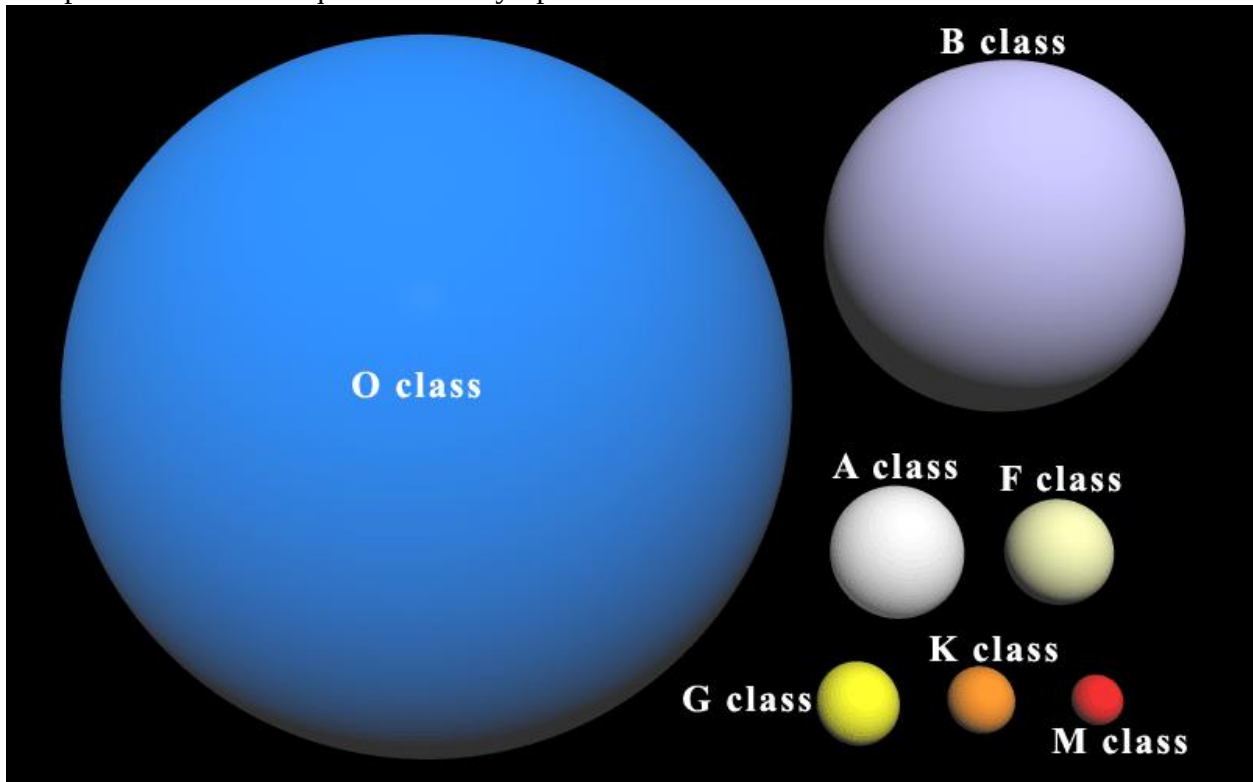
Stellar Comparisons

The images below offer some comparison between the different stellar primaries. The below images are true to scale. Note that these depict the *median* size of each star type, not the minimum or maximum size.

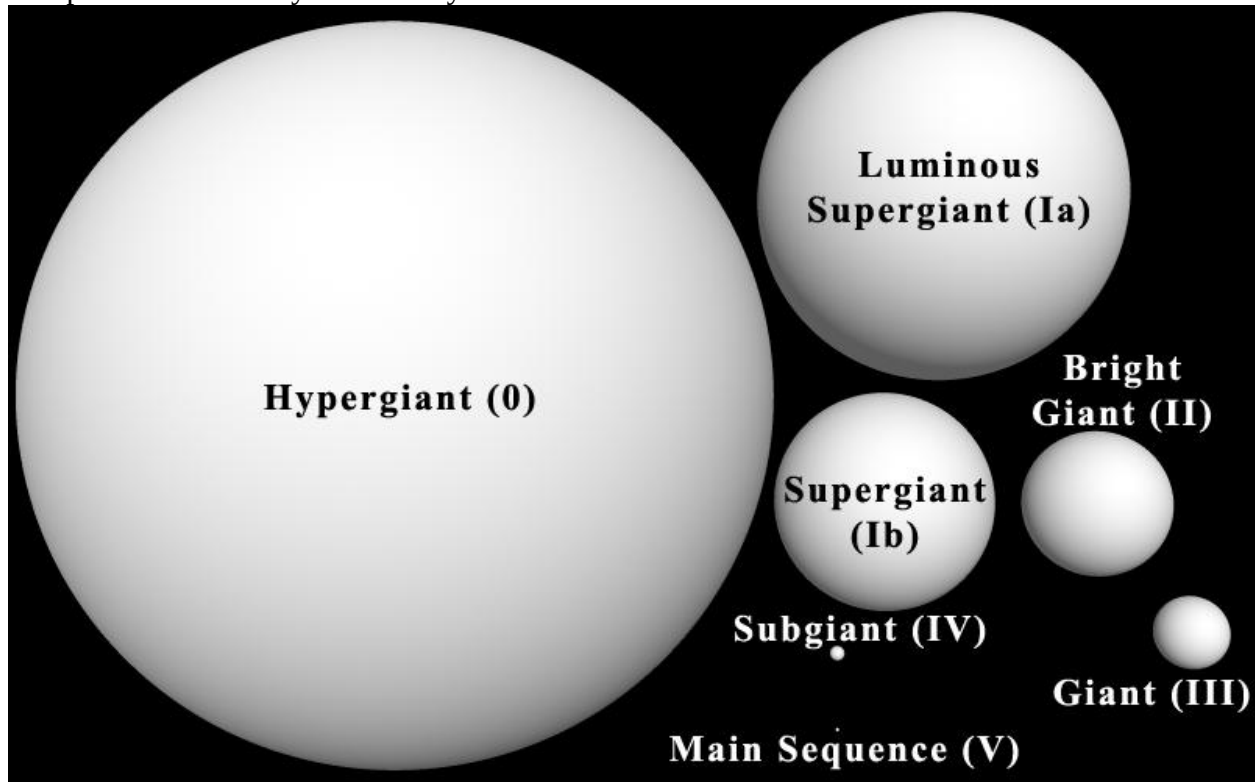
Comparison of Our Sun and Smaller Objects



Comparison of Main Sequence Stars by Spectral Class



Comparison of Stars by Luminosity Class



Main Sequence star is that little dot above the “q” in the text “Main Sequence.” For a very excellent video on size comparison, watch this video by [morn1415 at YouTube](#).

Approximate Lifetime of a Star

The below equation will give you the approximate lifetime of a star. Remember, this is the **entire** lifetime of the star, not how much lifetime is left. Also remember, this is only an approximation with a margin of $\pm 15\%$. And when you are dealing with numbers with exponents of 10, this means $\pm 1,500,000,000$. And the numbers just get larger after that.

$$T = (M^{-2.5}) \times 10^{10}$$

Where **T** = number of years; **M** = star’s mass in Sol units

Modified Hertzsprung - Russell diagram

Most Hertzsprung – Russell Diagrams plot stars using only the temperature and luminosity of a star. The modification I made is the addition of radii. The previous version of the HR Diagram was a program that plotted the curves using a star's Spectral Class/Level (temperature) and luminosity. When I sent the generated graph to my friend, he let me use a new program (over the WWW) that also plotted the star's radius with the star's luminosity. Both programs he allowed me to use as a favor to a friend. No, I cannot get him to let others use them. There is an additional appendix showing how to read the HR Diagram.

After using the below diagram, you can use the equations to further refine the luminosity and radius parameters.

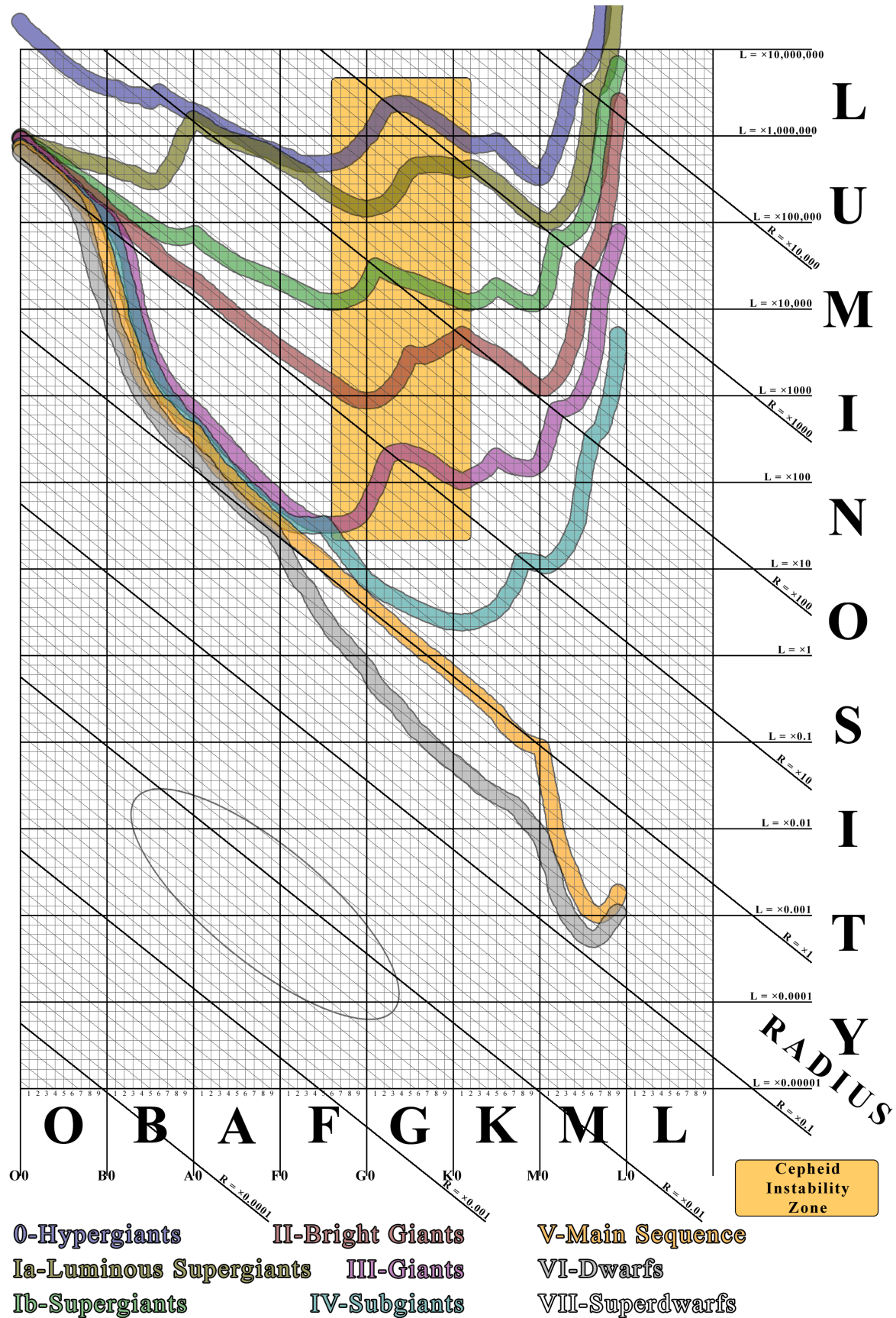
There is also a Cepheid Instability Zone where stars can become [Cepheid Variable](#) stars. These variables are not very amicable towards the development of life. Remember, stars in this zone have only a possibility of becoming a Cepheid Variable.

The both programs I used discount any star below the M9 class, thus no curves plot into the L class region.

The curves for the 0-Hypergiants and Ia-Luminous Supergiants end up going off the scale towards the M9 end of the curves. Just for example, the M9-0 Hypergiant ended up with a radius of 232,000 Sol Units (1.61356e11 kilometers). That is a radius 1079 times larger than the Earth's orbit!! Or, it is a radius almost 9 times larger than our entire stellar system, **including** the Kuiper Belt.

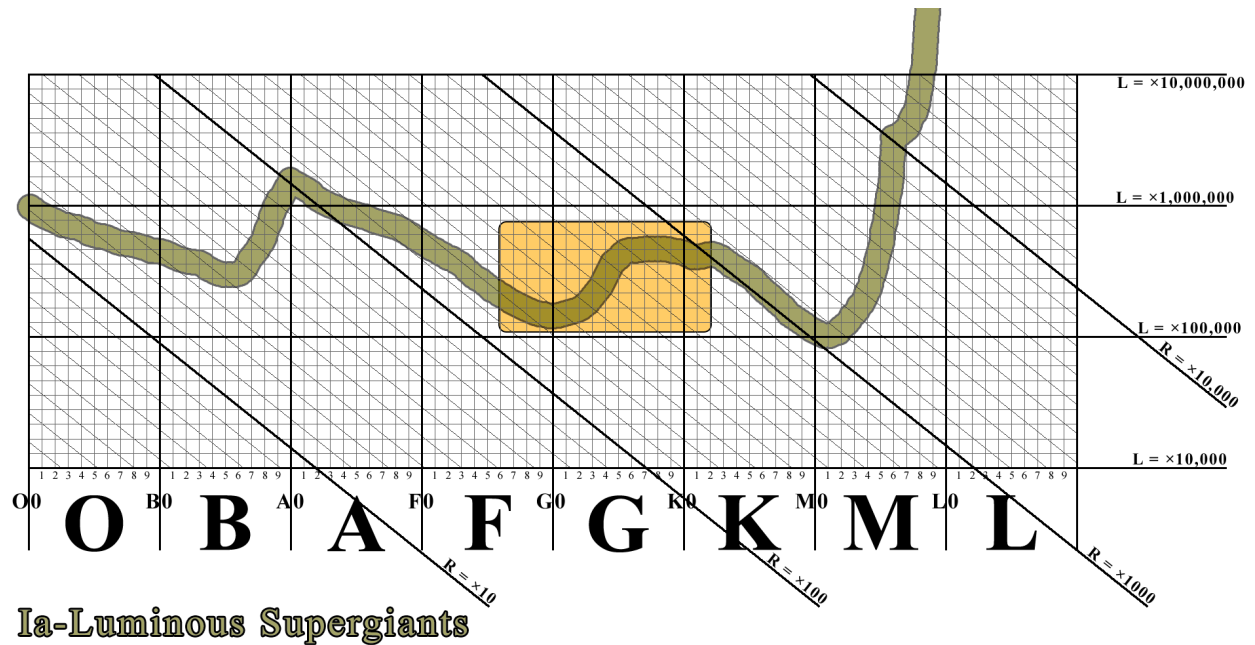
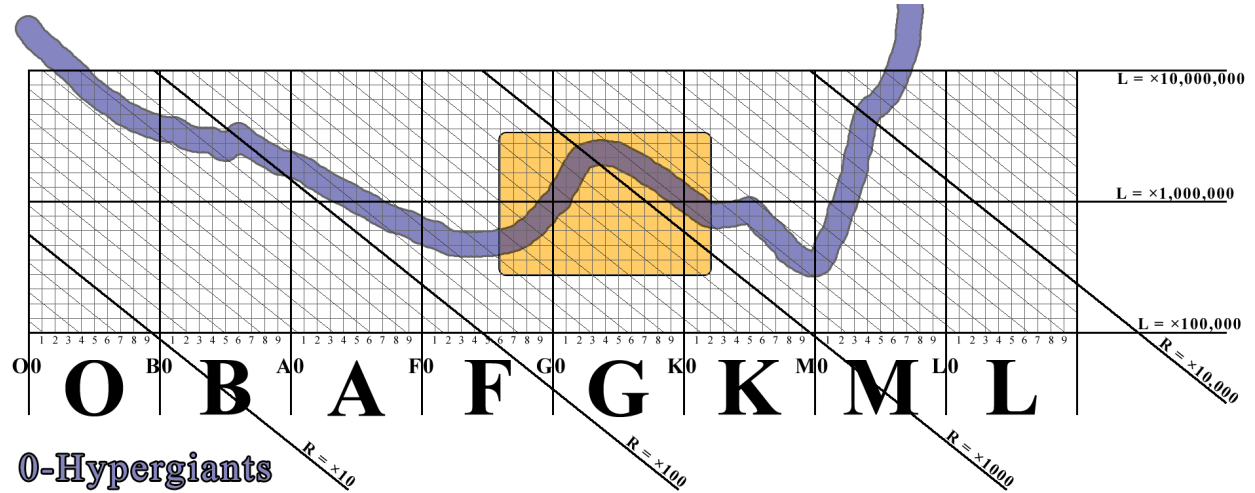
It still amazes me how the curves for those greater than Main Sequence generally follow a curve where the stars get larger as they get colder.

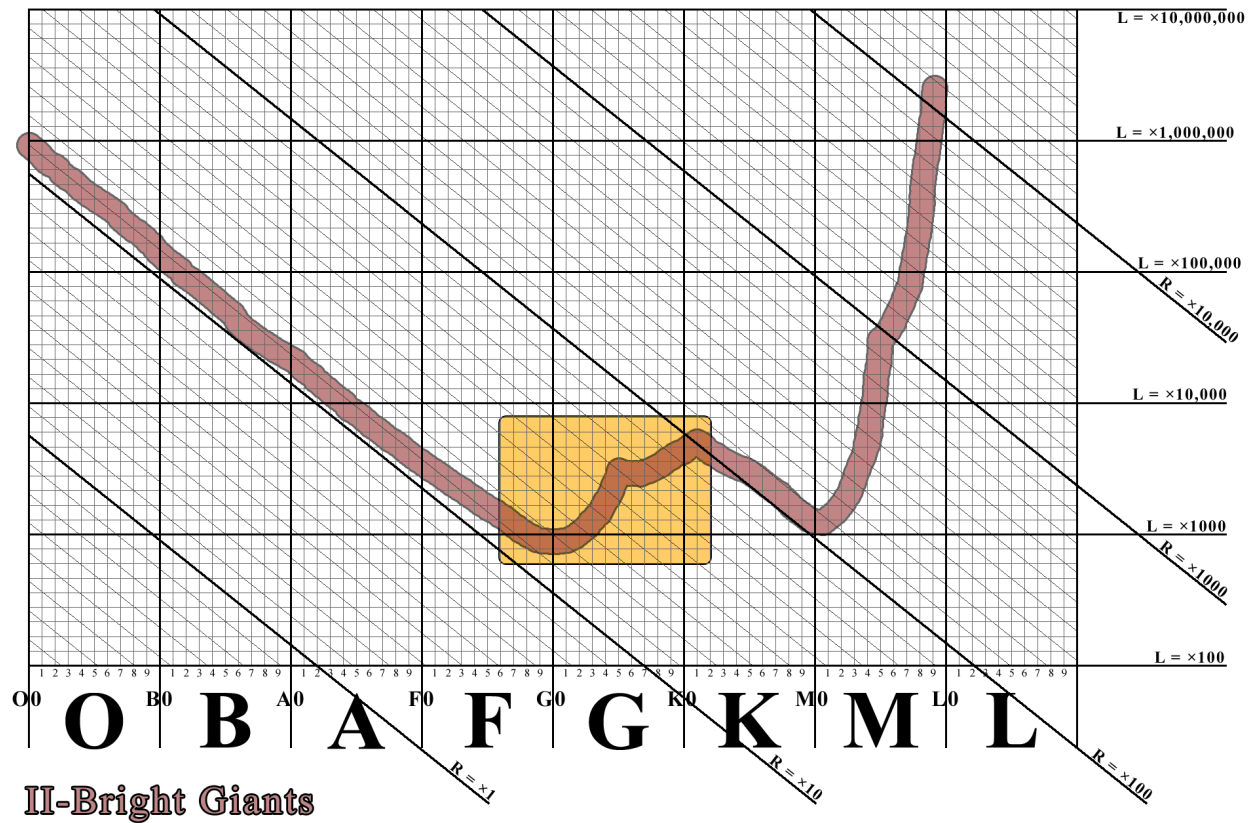
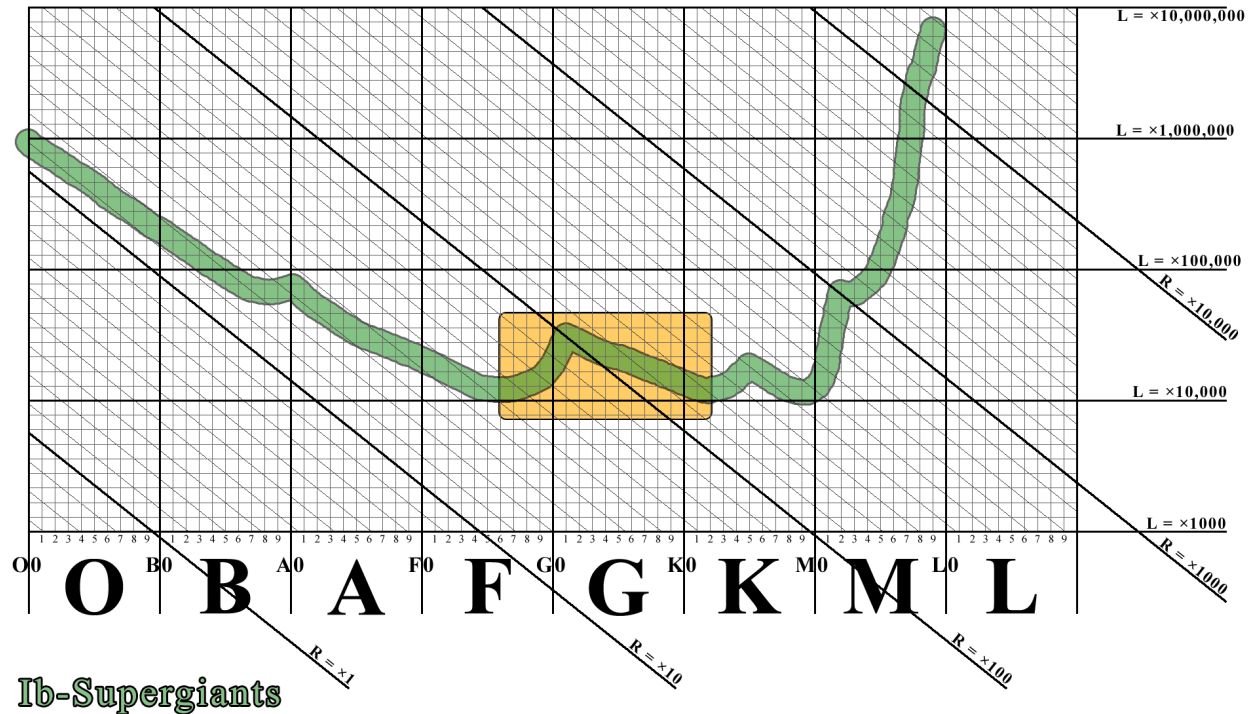
As far as I know (off the top of me head), we have found only two Hypergiants: the Pistol Star and [VY Canis Majoris](#) (VY). There is a great debate on the actual size of VY. Most say it has a radius of about 2100 Sol Units, making its size larger than the orbit of Saturn. Some few are saying its actual radius may only be about 600 Sol Units, making it slightly larger than the orbit of Mars. Read the article on Wikipedia linked above. At the current believed size of VY Canis Majoris, its density is only 0.000010 kg/m³. That is less dense than the Earth's outer atmosphere. Even the believed smaller size of 600 Sol Radii still only makes its density about 0.0002 kg/m³, which puts its density much closer to the average mean density of other red supergiants. However, it is still mind-boggling to think of a star that huge. As provided earlier in this document, here is an excellent video created by morn1415 on [size comparison](#).

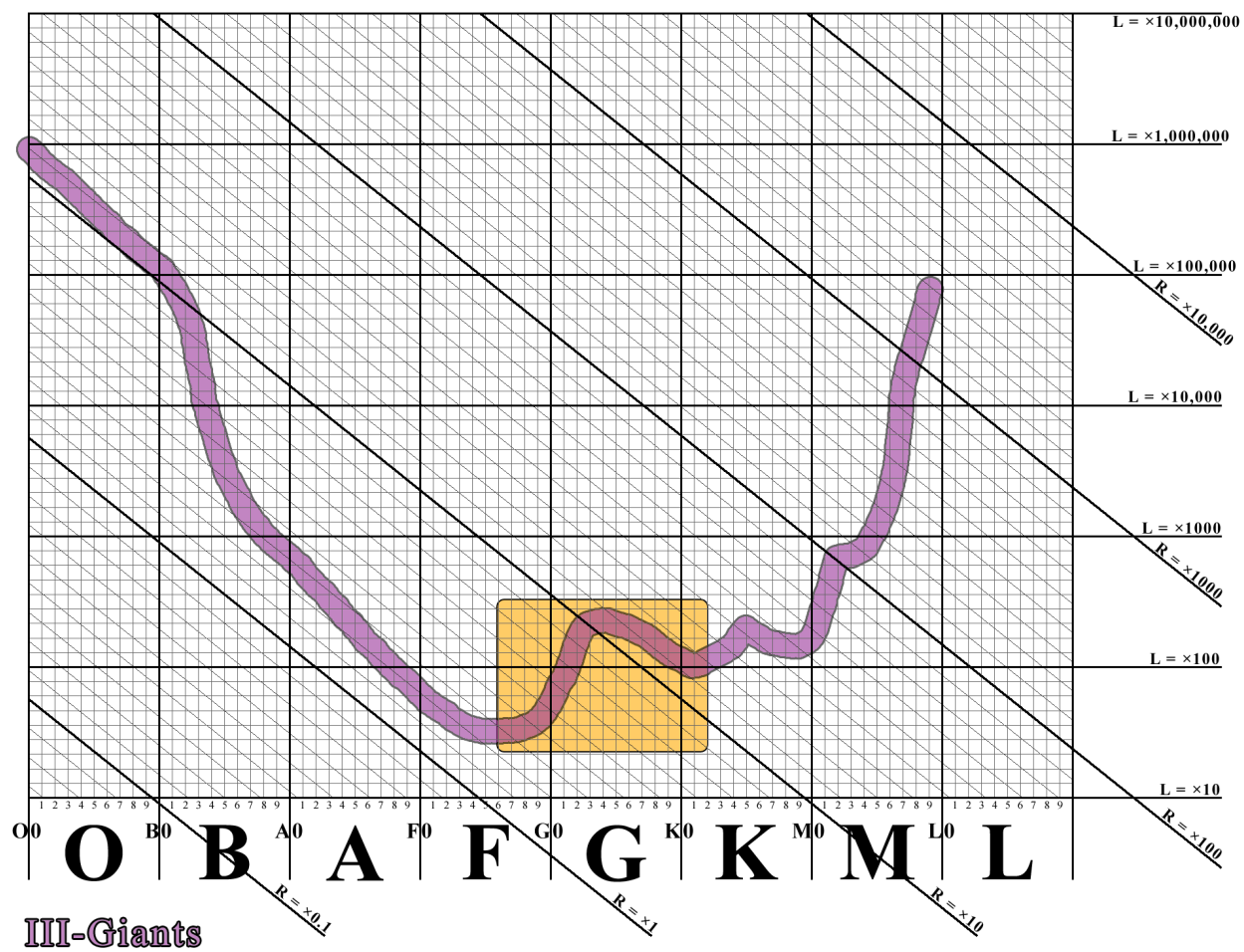


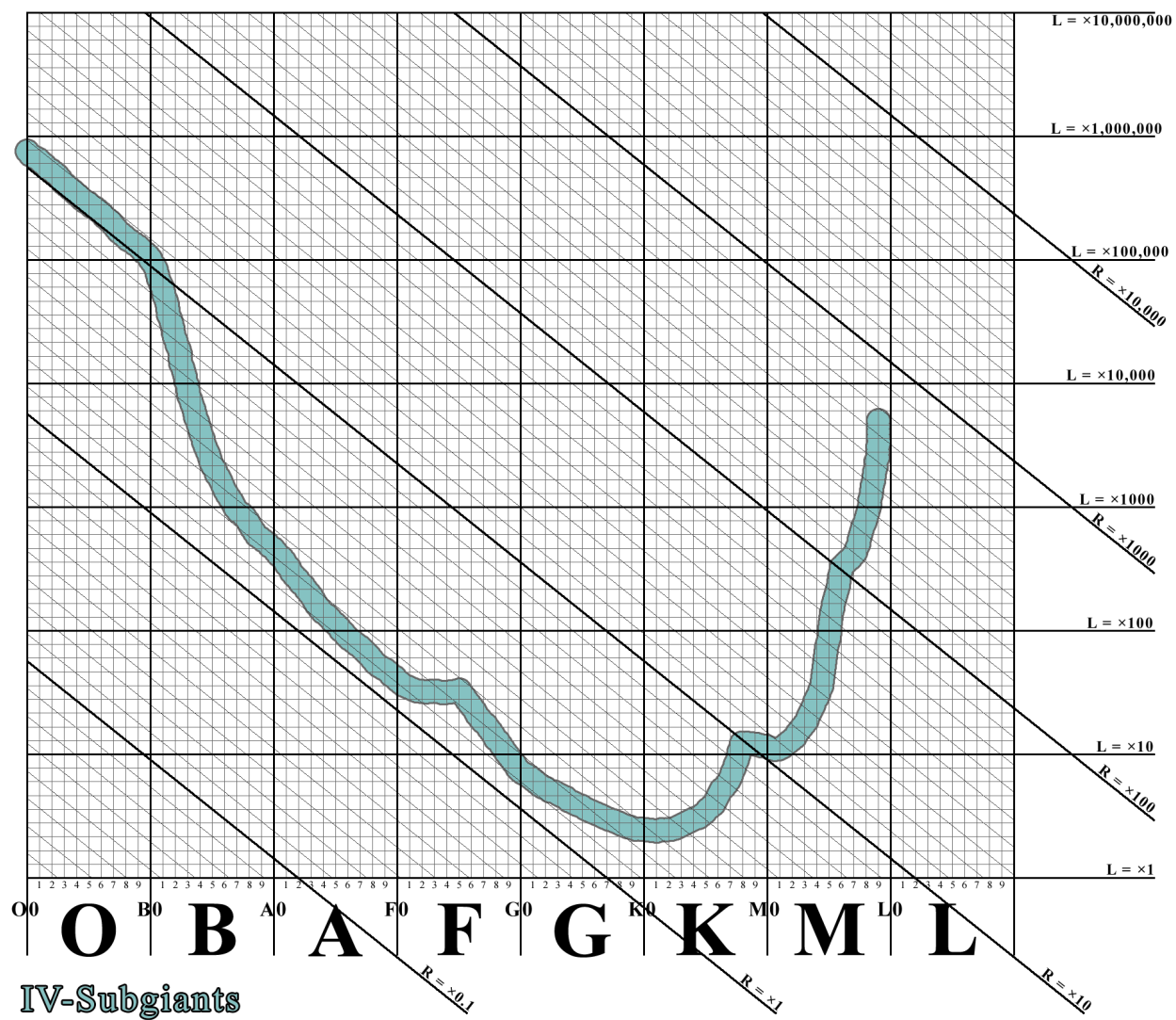
Individual Curves

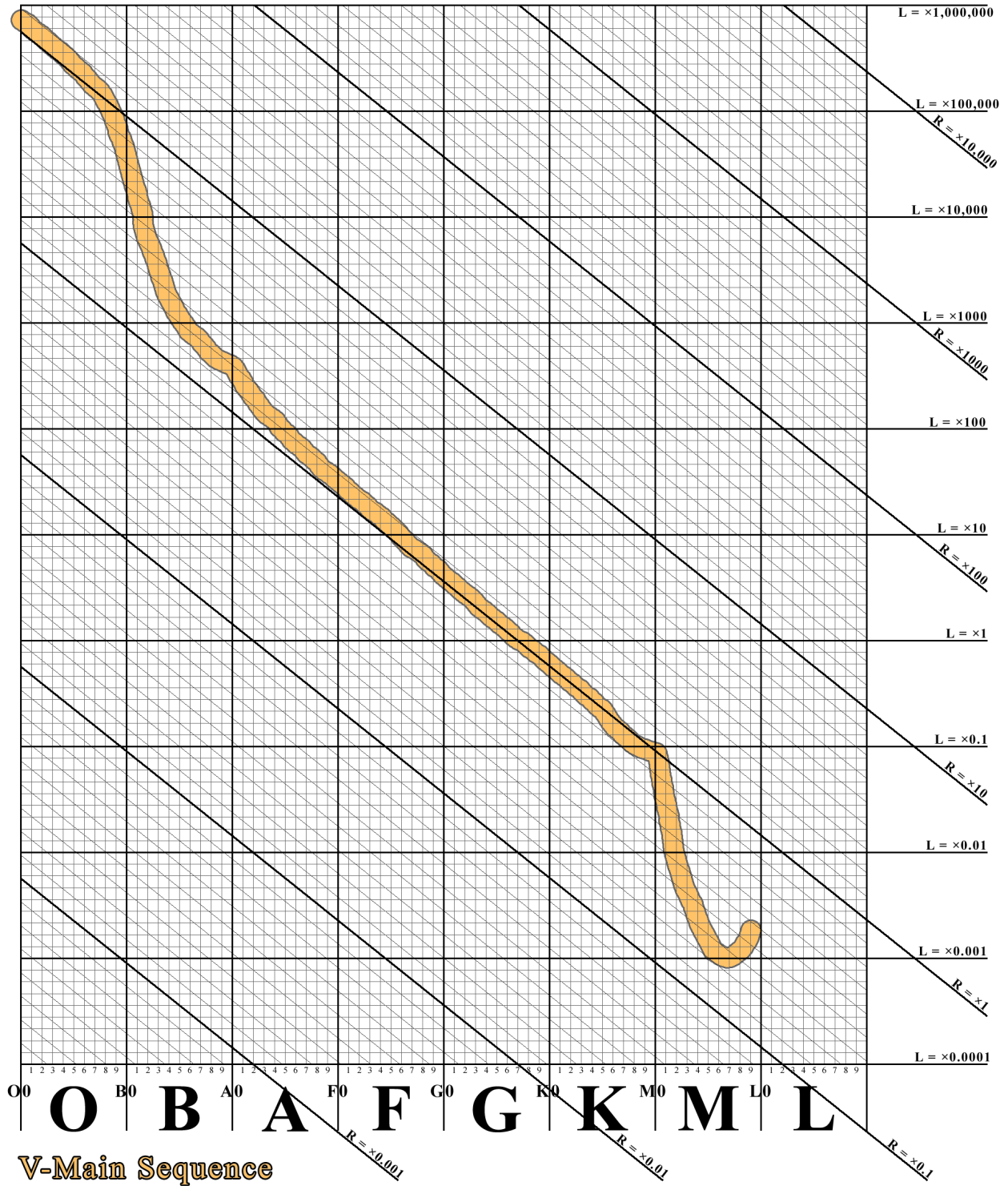
Herein follows images of the individual luminosity class curves since they merge in the O spectral class.

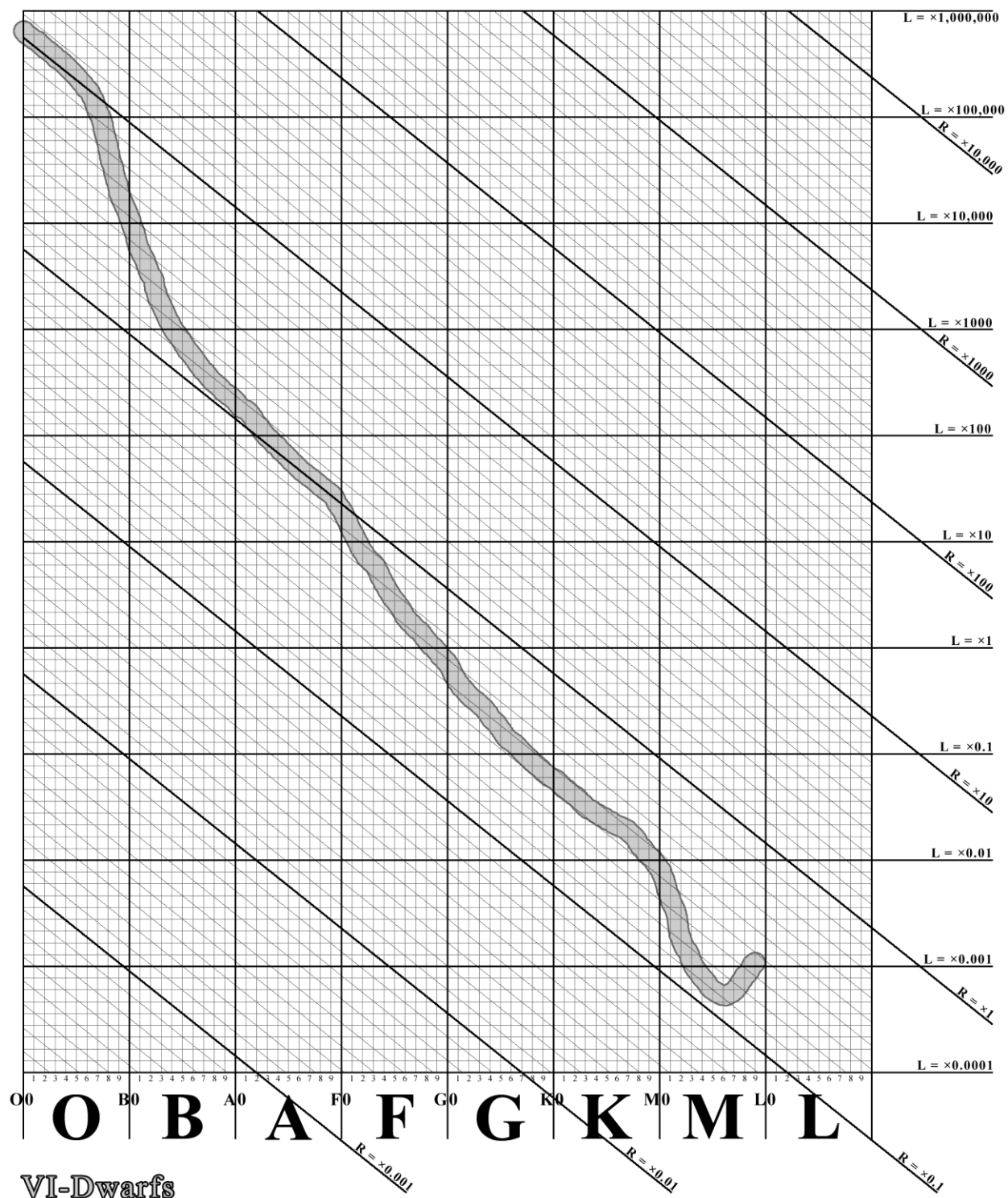












Chapter 4: Planets

Generating Orbits

Before going into generating parameters for the planets, we need to first determine if the system has a Prime Jovian or not. Jupiter is the Prime Jovian of our system. Prime Jovians will always outmass all other planets in the system combined. However, due to recent discoveries of stellar systems close to ours, we have been finding that systems with a Prime Jovian are perhaps more rare than systems without a Prime Jovian. Currently only about 1 in 5 systems we have discovered have a Prime Jovian. You can simply choose whether your system has a Prime Jovian or not, or you can use the below for random determination. Prime Jovians will be a Jovian with a minimum mass equal to Jupiter. For purposes of generating orbits, Giants are O and B spectral class stars, and stars of Luminosity Class III or greater. Majors are Main Sequence stars of A, F, G, and K spectral class, and Luminosity class IV and V. Minors are all others.

Star Type	Determination
Giant	01-90 = non-Jovian; 91-00 = Prime Jovian
Major or Minor	01-75 = non-Jovian; 76-00 = Prime Jovian

Orbital Paths

This is the number of possible planets the star may have. Luminosity class will modify the roll due to the fact that the larger a star is, the more massive it is, and the more massive it is, the less matter will be left behind to form planets. Although main sequence, the same holds true for the O and B class stars. All modifiers are cumulative.

Roll	Result	Luminosity Class	Modifier
01-25	none	0	-50
26-50	d5	Ia	-50
51-75	d8	Ib	-50
76-94	d10	II	-25
95-97	d10+2	III	-10
98-99	d10+5	IV	-5
00	2d10	all others	-0
		Spectral Class	Modifier
		O	-25
		B	-15
		A	-5
For non-Jovian system, add +25		all others	-0
For Prime Jovian system, add -6			

System with a Prime Jovian

For a system with a Prime Jovian, we first need to determine where it is located in the system. All systems have five orbital density zones: epistellar, inner system, middle system, outer system, and deep system. For this generator, Prime Jovians cannot be in the deep system orbits.

You may use the table below to determine randomly where the Prime Jovian is, or you may simply choose.

Roll*	Result – Notes
01-15	Epistellar orbit – planets cannot form in this orbit, but are dragged here by friction with the proto-planetary disk as the system is forming.
16-30	Inner System orbit – planets can form here rather easily. There is not as much material here as in the Middle System orbit, but it is closer together, allowing planets to form here easily.
31-90	Middle System orbit – the proto-planetary disc is at its thickest in this region and is the best region for a Prime Jovian to form. Though Prime Jovians can end up anywhere.
91-00	Outer System orbit – this is the outermost region for the formation of planets. Although the material in this region is more widespread, planets can still form here easily enough. If the Prime Jovian is in this region, there will be no other planets further out, only Kuiper objects.

* For Giant star systems, add +15 to this roll.

Beyond the Outer System orbits are the Deep System orbits. Outer Deep System orbits are reserved for extra-Kuiper and Kuiper objects since, most likely, these objects will primarily be ice balls. Another rule-of-thumb to keep in mind with any stellar system is that the closer to the star a planet is, the denser it will be. Only Venus (95% as dense as Earth) in our stellar system disobeys this general rule, and it is still not understood why. For example, Mercury is as dense as the Earth (and I forget where I read this on a NASA-JPL webpage). Mars is slightly more than two-thirds as dense as Earth. And the other planets just keep getting less and less dense. Remember, this is just a general rule-of-thumb. Generally, terrestrial type planets will be much denser than Jovian type planets. In fact, Saturn has such a low density (687 kg/m^3) that it would actually float on water (1000 kg/m^3). Now wouldn't that be a sight?

Now that we know where the Prime Jovian is, we can determine where other orbits will be. As always, you can simply choose. But do use the below for a guideline.

Number of orbits inside the Prime Jovian:

If the Prime Jovian is in an epistellar orbit: d4; 1-3 = 0, 4 = 1.

If the Prime Jovian is in an inner system orbit: d4; 1-2 = 0, 3 = 1, 4 = 2.

If the Prime Jovian is in a middle system orbit: d4; as rolled.

If the Prime Jovian is in an outer system orbit: d6; as rolled.

Now we need to figure out the mean orbital radius for the Prime Jovian. The table below lists the ranges for the five general orbit zones. The values in the below table are for a Sol-like star. For other stars, multiply the below listed values by the star's mass in Sol units. If not recorded, divide the star's mass by 1.98892e30 to convert to Sol units. All values are listed in AUs.

Orbital Zone	Minimum	Maximum
Epistellar	0.02	0.2
Inner	0.2	2
Middle	2	8
Outer	8	20
Deep	20	Oort Cloud

If desired, you can choose an orbital radius from within the above ranges. Or, you can use the below table for randomness. Remember to multiply the rolled value by the star's mass in Sol units.

Epistellar		Inner		Middle		Outer	
Roll	Result	Roll	Result	Roll	Result	Roll	Result
01-10	0.02	01-10	0.2	01-07	2	01-07	8
11-30	0.04	11-20	0.4	08-15	2.5	08-15	9
31-50	0.07	21-30	0.6	16-23	3	16-23	10
51-70	0.1	31-40	0.8	24-31	3.5	24-31	11
71-90	0.15	41-50	1	32-38	4	32-38	12
91-00	0.2	51-60	1.2	39-46	4.5	39-46	13
		61-70	1.4	47-54	5	47-54	14
		71-80	1.6	55-62	5.5	55-62	15
		81-90	1.8	63-69	6	63-69	16
		91-00	2	70-77	6.5	70-77	17
				78-85	7	78-85	18
				86-93	7.5	86-93	19
				94-00	8	94-00	20

Alright, now we know exactly where the Prime Jovian is. Now we can determine where the other planets' orbits are. Remember, we already determined the number of orbital paths above and how many are inside the Prime Jovian. However, if you generated a Prime Jovian in the 0.02 AU orbit, then there will be no planets inside. Additionally, if you did generate a planet inside an epistellar Prime Jovian, then that planet is at the 0.02 AU orbit and the Prime Jovian will be at the 0.04 AU orbit. Please remember that the 0.02 and 0.04 AU orbits may be further out or closer in since they are modified by multiplying by the star's mass in Sol units.

To determine the orbits for the other planets, use the Prime Jovian as the Foundation Planet. Then, use the below listed method for calculating where the other planets are.

For planets inside the Prime Jovian, begin with the next orbit inside and *divide* the Prime Jovian's orbit value by $(1.3 + (d12 \div 10))$. Record this value and use it as the basis for the next orbit inside and repeat until you have determined the orbit values for all planets inside the Prime

Jovian. If any planet's orbit ends up less than the 0.02 AU orbit, then disregard and move it outside the Prime Jovian. Please remember the 0.02 AU orbit may be of a different value modified by the star's mass. (Old writer's law: Tell the reader three times to make it sink in.)

For planets outside the Prime Jovian, begin with the next orbit outside and *multiply* the Prime Jovian's orbit value by $(1.3 + (d12 \div 10))$. Record this value and use it as the basis for the next orbit outside and repeat until you have determined the orbit values for all planets outside the Prime Jovian.

System without a Prime Jovian

Generally, systems without a Prime Jovian will tend to have more planets than systems with one. This is mainly due to more stellar matter being available for more planets. For a non-Jovian system, the most important planet orbit is the Foundation Planet. For this type of system, it is the innermost orbit. Use the below method for calculating planet orbits.

Foundation Planet Mean Orbital Radius (MOR)

- 1) Roll d1000, summing results until total is ≥ 500 .
- 2) Divide result of Step 1 by 1000.
- 3) Multiply result of Step 2 by the star's mass in Sol units.
- 4) Result is the MOR in AUs. To convert to meters, multiply by 149,597,870,691.

Now that we know where the Foundation Planet is, the remaining planets are fairly easy. Using the MOR of the Foundation Planet, simply multiply its orbit value by $(1.3 + (d12 \div 10))$. Record this value and use it as the basis for the next orbit outwards and repeat until you have determined the MOR values for each of the Orbital Paths determined above.

Now we're ready to generate the data for our planets. Remember, if all you want is the data for your focus planet; just simply skip all the other planets.

Physical Characteristics

Type

Planets come in a myriad of types. Basically there are two broad categories of planets: terrestrial and Jovian. Terrestrial planets are similar to Mercury, Venus, Earth, and Mars. Jovian planets are similar to Jupiter, Saturn, Uranus, and Neptune. After I first read about the [Kuiper belt](#) and Kuiper objects, way back in 1976, I ceased to consider Pluto a planet. Instead I classified it as a Kuiper object. My logic was based on Pluto's orbit when I once commented in class, "Because of its orbit, Pluto looks like a giant captured comet." To which the teacher replied, "Or it's a Kuiper belt object." Which in turned caused me to study up on what the Kuiper belt was. Since then, in 2006, the IAU has now classified these larger Kuiper objects as [Plutoids](#). Here is a decent article on [planet classification](#) at Wikipedia.

The Deep System

Beyond 20 AUs (modified by star's mass) is the Deep System. This is a region where, normally, planet formation is improbable. However, planets can be found out here due to a phenomenon known as "[scattering](#)." During the Newborn and Young phase of a star, planetary orbits are highly susceptible to change. Close encounters with other planets or gravimetric resonance interference from more massive planets can throw or push other planets into deeper regions of the stellar system. I once read a theory that suggested Uranus and/or Neptune may have started in the region now occupied by the asteroids and was pulled out by Jupiter/Saturn. Later, Jupiter/Saturn flung them out into the deep system, where they currently reside. If true, this could easily explain the asteroids since they were left behind and shepherded by Jupiter and Mars. This could also explain why Uranus rotates on its side with an axial tilt of almost 98°. As it was flung outwards, it was also pulled over onto its side. There are also theories that Uranus and Neptune were once a single planet and were pulled apart by the same flinging that threw them into the deep system. My theory is that all planets form within the Inner, Middle, and Outer System orbits, with orbits that are much closer than now, then later scatter themselves inward/outward, following the [Keplerian Laws of Planetary Motion](#).

Asteroid Belts

Asteroid belts deserve some special mention. An asteroid belt cannot exist as the outermost orbit. If you generate such in the outermost orbit, simply ignore the result and reroll until you get a planet. Two asteroid belts cannot be generated in two successive orbits. Once you generate an asteroid belt, ignore any asteroid belt results in the next orbit.

Note: Always remember that you can choose which type you desire at each orbit. Also remember that no Jovian may be larger than the Prime Jovian.

Planet Type

Epistellar Orbits		Inner System Orbits		Middle System Orbits	
01-27	Lunan	01-24	Lunan	01-19	Lunan
28-46	Terran	25-44	Terran	20-31	Glacial ²
47-62	Pyrosubjovian	45-55	Pelagic	32-44	Terran
63-92	Pyrojovian	56-60	Oceanic	45-55	Pelagic
93-00	Pyrosuperjovian	61-65	Vesuvian	56-60	Oceanic
		66-70	Furian	61-65	Vesuvian
		71-73	Asteroid Belt	66-70	Furian
		74-82	Subjovian ¹	71-73	Asteroid Belt
		83-92	Jovian ¹	74-82	Subjovian ³
		93-98	Superjovian ¹	83-92	Jovian ³
		99-00	Hyperjovian ¹	93-98	Superjovian ³
				99-00	Hyperjovian ³

Outer System Orbits		Deep System Orbits		Transplanetary Region	
01-23	Lunan	01-23	Lunan	01-67	Lunan
24-44	Glacial	24-44	Glacial	68-00	Glacial
45-54	Pelagic ⁴	45-58	Pelagic ⁴		
55-62	Asteroid Belt	59-64	Asteroid Belt		
63-82	Cryosubjovian	65-00	Cryosubjovian		
83-92	Cryo jovian				
93-98	Cryosuperjovian				
99-00	Cryohyperjovian				

Footnotes in Above Tables

1 – Pyro type in the inner third of region; Cali type otherwise.

2 – Only in the outer two-thirds of region; treat as Terran otherwise.

3 – Cali type in the inner third of region; Frigi type otherwise.

4 – As Glacial type, just more massive.

Special Note: No other Jovian type may be more massive than the Prime Jovian. Largest acceptable mass is $\times 0.5$ that of the Prime Jovian.

Explanation of Planet Types

Planetary bodies come in many myriad forms. They come in many different sizes and chemical makeup, from immense spheres of fluidic gas massive enough to outmass all other planets in their systems, arid and dusty rock balls, to oceanic worlds brimming with life. Planets are divided into two broad categories: Terrestrial and Jovian.

Jovian Planets

Jovian planets are usually called “gas giants.” The term “gas giant” was coined by science fiction author James Blish in 1952 in his story *Solar Plexus*. Arguably the term is something of a misnomer since throughout most of a Jovian’s volume; all of the constituents are above the critical point. Therefore, there is no clear-cut difference between ices, liquids and gases. Fluidic planet is a more accurate term. Generally, Jovian planets have no solid surface except for a small core of rock and metal. The rather misleading term of “gas giant” has caught on because planetary scientists tend to use the terms “rock,” “gas,” and “ice” as catch-all terms for the constituent elements contained within the planet, regardless of what phase (gas, liquid, solid) the matter is in. Especially in the outer system, hydrogen and helium are referred to as “gases”; water, methane, and ammonia as “ices”; and silicates and metals as “rock”. When considering the deep interiors of Jovian planets, “ice” means oxygen and carbon, “rock” means silicon, and “gas” means hydrogen and helium. Jupiter is an exception since it has a metallic hydrogen outer core which generates a lethal magnetic field much stronger than the Earth’s. The Earth’s magnetic field measures about 0.3 gauss at the surface while Jupiter’s measures about 4.28 gauss (about 14 times as powerful).

Jovians come in four types: subjovian, Jovian, superjovian, and hyperjovian. They also come in four subtypes based on temperature: pyro-, cali-, frigi-, and cryo-. Since all Jovians share similar compositions, only temperature makes a difference to their prime chemical makeup.

Nomenclature plus the prefix differentiates the Jovian types. Mass Ranges are listed in multiples of Jupiter masses (1.8986×10^{27} kg) and abbreviated by “Mj.”

Subjovian

Mass Range: 0.03 to 0.3 Mj

Uranus and Neptune in our stellar system are examples of this type of planet. Although subjovians have a smaller core than a Jovian, that core makes up more of its overall mass and volume. The predominance of hydrogen and helium is usually replaced by ammonia and methane and other hydrocarbons. Like Uranus and Neptune, this will tend to cause subjovians to have a greenish or bluish tint. Subtypes: pyrosubjovian, calisubjovian, frigusubjovian, and cryosubjovian.

Jovian

Mass Range: 0.3 to 3.5 Mj

Saturn and Jupiter in our stellar system are examples of this type of planet. These planets are dominated by hydrogen and helium, but can possess other gases in minute amounts. For example, Jupiter is composed of 89% molecular hydrogen, 10% helium, 3000ppm methane, 260ppm ammonia, 28ppm hydrogen deuteride, 6ppm ethane, 4ppm water, and in minute amounts, the aerosols of ammonia ice, water ice, and ammonia hydrosulfide. Saturn has a very similar composition. Depending on either the amount of energy received or energy produced in the core, these planets can have the most monstrous weather of any planet, excepting the super and hyperjovians. If there is very little energy, then the weather will be more subdued like the subjovians Uranus and Neptune. Subtypes: pyrojovian, calijovian, frigijovian, and cryojovian.

Superjovian

Mass Range: 3.5 to 8 Mj

With no contemporary examples, these planets are still similar to Jupiter, just more massive. Superjovians will only be about up to 2 times the size of Jupiter. Planets tend to become denser with a smaller size than expected when they become more massive. This same tendency also holds true for terrestrial planets. As a general rule-of-thumb, take the fourth root of the planet's mass in Jupiter units (or Earth units for terrestrial) to get the size increase. Please note that this rule-of-thumb does not work for planets with a mass factor ≤ 1 . Subtypes: pyrosuperjovian, calisuperjovian, frigusuperjovian, and cryosuperjovian.

Hyperjovian

Mass Range: 8 to 15 Mj

These are the true giants of planets. More often than not, if a stellar system has one of these, it will rarely have any other planets, or the other planets will be of much less mass. Additionally, hyperjovians will tend to have a highly elliptical orbit which cause them to sweep away almost the entire protoplanetary disk as the stellar system is forming, leaving little matter for other planets to form. The 13 Mj mass is the generally accepted upper limit for a gas giant. However, the difference between a hyperjovian and a brown dwarf is very subtle and not very easy to determine. Essentially, the main difference between a hyperjovian and a brown dwarf is whether

it is fusing deuterium in the core. Also, there are some hyperjovians currently believed to have masses up to 20 Mj. Thus, I set the maximum at the lower end of the 13 to 20 Mj range. Subtypes: pyrohyperjovian, calihyperjovian, frighyperjovian, and cryohyperjovian.

Pyro-

From the Greek “pyro” meaning “fire.” This prefix is used for Jovian types within the epistellar zone. Jovian type planets will evolve into a Lunan or Terran type terrestrial planet. However, this can take 8 to 15 billion years. Thus, if the star is Newborn, Young, or Mature, the Jovian type planet will still exist. Jovians and larger can begin to take on the visual characteristics of brown dwarfs, but they still may not be fusing deuterium.

Cali-

From the Latin “calidus” meaning “warm.” This prefix is used for Jovian types within the inner system zone. Subjovians can evolve into Terran, Pelagic, or Oceanic type terrestrial planets, or become “gas dwarfs.” Jovians and larger tend to take on a deep azure color as more of the constituent elements are forced to form more methane from the increased energy (object flux) received.

Frigi-

From the Latin “frigidus” meaning “cold.” This prefix is used for Jovian types within the middle and outer system zone. All Jovian types will be characterized by banded cloud layers from various ices of water, ammonia, and methane as well as the formation of other hydrocarbons and dioxides. These planets can range from whitish, through yellowish to reddish-brown or orangish-brown. You can use Jupiter and Saturn for example appearances.

Cryo-

From the Greek “kryos” meaning “ice cold.” This prefix is used for Jovian types within the deep system zone, although some can lie within the outermost outer system zone. This subtype of Jovians is also called “ice Jovians.” The deep chill of the deep system zone causes thick atmospheres with little structure since there is little energy (heat) to generate weather. Cirrus-like clouds of water and/or ammonia ice crystals can form and last for weeks, months, perhaps years.

Terrestrial Planets

Terrestrial planets may be the most common type of planet in the universe. Most of these terrestrial exoplanets discovered are referred to as “superearth” due to their mass and size. Currently, we are probably unable to detect anything other than these superearth. But that may not remain so for long. Even using our stellar system as an example, there are only 4 Jovian types compared to 9 terrestrial planets. Although the Moon, Callisto, Ganymede, Io, and Titan are satellites themselves, they qualify as terrestrial planets since their mass is within the lower limit of 0.01 Me (5.9736e22 kg). The Moon is a special case since it has less mass than its size would suggest. The main hypothesis that may explain this fact is the “[giant impact hypothesis](#).” This hypothesis states that a Mars sized planet (named Theia) may have formed in Earth’s L5 Lagrange Point and drifted into the Earth. This impact caused much of the less dense crustal material of both planets to be ejected into space which later formed the Moon. The denser metal

core material sank into the Earth, giving Earth its current dynamic nickel-iron outer and inner cores. Mass, composition, and location in the system play a large role in the formation of the terrestrial type planet. They also come in a larger variety than the Jovian type. A general rule-of-thumb for terrestrial type planets is the closer to the star a terrestrial is, the more dense it will be, and thus richer in metals. Mass Ranges are listed in multiples of Earth masses (5.9736×10^{24} kg) and abbreviated by “Me.”

Lunan

Mass Range: 0.01 to 0.25 Me

From the Latin “luna” meaning “moon”. Mercury, Mars, and the Moon are good examples of this type of terrestrial planet. Most often, this type of planet is too small to hold onto any appreciable atmosphere. Any atmosphere that does exist will be much too thin to support any kind of life, except perhaps some of the hardiest bacteria and/or protozoa. These planets are also characterized by having little or no geological activity. Landforms are usually very ancient, perhaps dating almost back to the very beginnings of the stellar system. Some of the larger lunans may still have some geological activity if the system is Young or Newborn.

Glacial

Mass Range: 0.01 to 0.5 Me

From the Latin “glacialis” meaning “ice”. Ganymede, Callisto, and Titan are good examples of this type of terrestrial planet. Europa is a borderline glacial and very small pelagic/oceanic. Although the name of this type derives from “ice,” it does not mean that this type of terrestrial is completely frozen. Ones in the deep system zone may be completely frozen. Glacials will usually have a lot of water, which forms an icy crust over the inner rocky mantle. Some may even have enough internal heat, either due to tidal forces or their own internal heat, to form oceans below the icy crust. The “ices” need not be water. Ices also include methane, as with Titan, ammonia (no contemporary example), carbon dioxide (perhaps Pluto-Charon), and oxygen, amongst others. This also depends on the temperature of the glacial planet. Here is a partial list of the temperatures (approximate) which form ices: Water 273K (0C, 32F); Methane 90K (-183C, -297F); Ammonia 195K (-78C, -108F); Carbon Dioxide 195K (-78C, -108F); Hydrogen 14K (-259C, -434F); Ethane 89K (-184C, -299F). [K = degrees Kelvin, C = degrees Celsius, F = degrees Fahrenheit]

Terran

Mass Range: 0.5 to 1.25 Me

From the Latin “terra” meaning “ground”. Terrans are a more massive version of the Lunan type terrestrial. The major difference between terrans and pelagics is water. Terrans usually have very little water, if any. Terrans usually form in the innermost Inner System zone, or are dragged into the outermost epistellar zone. Due to their proximity to the system’s star, terrans will usually form into hellish greenhouses like Venus. Since terrans have little standing water, it does not play a large role in the geological processes of the planet. Plate tectonics are virtually impossible on a terran since the crust tends to be thick, except on hotspot locations. Where vulcanism does exist, it is usually in the form of shield volcanoes over hotspots. Even if there is little geological activity, the searing flux some of these planets receive can still turn a terran into a hellish greenhouse since only the heaviest gases can be held by the planet’s gravity. Mars is another example of a smaller terran.

Pelagic

Mass Range: 0.5 to 1.5 Me

From the Greek “pelagus” meaning “sea”. Pelagics are virtually like our Earth with oceans that can cover 30 to 90% of the planet’s surface. Pelagics will be fairly geologically active since the water lubricates the crustal layer generating plate tectonics. The crust will usually be fairly thin and broken into plates. These plates tend to move across the surface of the planet creating convergent and divergent boundaries and seafloor spreading zones. This recycling of crustal material means the land will be relatively young (usually less than 500 million years old).

Oceanic

Mass Range: 1.5 to 3 Me

From the Latin “oceanus” meaning “ocean”. Oceanic type planets are usually the remains of a subjovian. They are more massive than the pelagic type, and are usually covered in their entirety with water ($\geq 90\%$ oceans). However, there may be chains of islands formed from volcanoes due to subduction zones with the underlying rock/metal core. These planets can be teeming with life, even more so than our Earth. Of course, all vulcanism can be hidden beneath tens to hundreds of kilometers of ocean. Oceanics can be larger than Vesuvian due to the layer of water which is less dense than rock and metal.

Vesuvian

Mass Range: 3 to 8 Me

From the Latin “vesuvius” meaning “volcano”. Terrestrial planets beyond 3 Earth-masses lose all pretense of Earth-like behavior. The crust becomes much thinner as the planet is in turmoil of barely contained heat. Vesuvian planets are massive enough to have an overall mean density approaching that of [lead](#) or greater. This greater density means the vesuvian will tend to possess a much greater amount of actinide metals than the less massive terrestrials. This greater amount of actinides produces a greater amount of internal heat. This means vesuvian types possess constant vulcanism and megavulcanism. The atmosphere tends to be thick and dominated by carbon dioxide, sulfur dioxide, hydrogen sulfide, and hydrogen cyanide. If there is any water on a vesuvian, it is invariably in the form of vapor. Standing water is not impossible on these hellish worlds, just highly improbable. However, some vesuvians may possess some small seas in which only the hardest primitive life can exist.

Furian

Mass Range: 8 to 14 Me

From the Latin “furia” meaning “rage”. These truly hellish worlds are the most massive, most dense, and largest of the terrestrial type planets. The furian planet makes a vesuvian type look pleasant by comparison. If there are any crustal rafts on this type of planet, it is paper thin (1 to 5 km thick) and fairly small in area (a few million square kilometers). Usually, a furian is nothing more than ball of blistering and boiling lava. The atmosphere is similar to the furian, except it is denser and thicker and more like a blast furnace with temperatures that could almost approach the melting point of iron (1811K, 1538C, 2800F). No life can survive on a furian unless it is a life form that can exist in the molten environment.

Some terrestrials massing 5 to 10 Me may also evolve to be gas dwarfs. The term “gas dwarf” has been used to refer to planets smaller than gas giants, but possess thick hydrogen and helium atmospheres. Usually, a gas dwarf is the remains after a higher mass vesuvian or furian that has lost the nuclear fission furnace of the heavier actinide metals which have broken down to lighter metals and minerals. Once enough cooling has occurred, their atmosphere will settle down into a composition similar to a Jovian type planet. However, it is calculated to take about 10 to 15 billion years for this to happen. If the star is Newborn, Young, or Mature, there will be no gas dwarfs. If the star is Old, you may change any Vesuvian or Furian to a gas dwarf if desired.

Asteroid Belts

Is there anyone who does not know what an asteroid belt is? Especially after the film *The Empire Strikes Back*? There are many methods by which an asteroid belt may form.

- A particular region of the protoplanetary disk could have simply failed to coalesce into a planet.
- Debris from elsewhere in the system could be shepherded into the region where a planet never formed.
- Two bodies of near same size could have begun to form and later impacted, completely disrupting both. FYI: It would take a planet about 60% the size of the Earth to completely disrupt both into an asteroid belt.
- A forming planet could have been torn apart by another more massive.
- A subjovian could have begun forming here and was flung out into the deep system leaving the debris behind.

However it formed, what is left is an asteroid field. Although asteroids can exist anywhere in the system, this belt is a major object in the system. We only have our asteroid belt as an example. Our asteroid belt has enough mass to make a planet perhaps the size of the Moon. This does not mean an asteroid belt could have even more mass. Perhaps even enough to have formed a furian. However, the SSG only generates asteroid belts with a total mass up to two Earth-masses.

Roll	Belt Size and Orbit Coverage	Belt Density	Mass Range (Me)
01-20	Tiny (45°)	Sparse	0.001 to 0.01
21-40	Small (90°)	Light	0.01 to 0.1
41-60	Medium (180°)	Moderate	0.1 to 0.5
61-80	Large (270°)	Dense	0.5 to 1.0
81-00	Huge (360°)	Very Dense	1.0 to 2.0

Roll for each aspect separately.

Special Note: There is an app included (SSGCalc.exe) that will calculate the next several parameters. All you will need is a working Volumetric Mean Radius, working Density, and Rotational Period. You can also enter a Land Percentage but only if you wish Land Area and Ocean Area calculated for you. The list of parameters that CelBodCalc.exe will calculate are: Mass, Volume, Mean Density, Equatorial Radius, Polar Radius, True Volumetric Mean Radius, Oblateness, Inverse Flattening Ratio, Surface Gravity, Escape Velocity, Total Surface Area, Land Area, and Ocean Area. I also include the equations with each of these parameters below.

Mean Density

This is fairly easy to calculate. First, determine the planet's mass and volume. Then divide mass by volume to get overall mean density. Remember, this is the overall mean density. All planets will vary in their density through the layers from surface to core.

$$D = \frac{M}{V}$$

Where **D** = mean density in kg/m³; **M** = mass in kilograms; **V** = volume in cubic meters.

Some sample Density Ranges; listed in kg/m³ (for use with CelBodCalc.exe)

Terrestrial Type	Density Ranges	Jovian Type	Density Ranges
Lunan	2500-4000	Subjovian	500-1800
Glacial	1500-3000	Jovian	500-2000
Terran	2500-5000	Superjovian	1500-4000
Pelagic	3500-6500	Hyperjovian	2500-5000
Oceanic	4000-7000		
Vesuvian	5500-9000		
Furian	7500-12,000		

Oblateness

All celestial bodies that rotate are actually [oblate spheroids](#). Oblateness is simply the amount of flattening of a planet caused by [centrifugal force](#). An oblateness of 1 indicates a perfectly flat disk, where an oblateness of 0 indicates a perfect sphere.

Oblateness from Equatorial and Polar Radii $f = \frac{a - b}{a}$	Oblateness from Density and Rotation $f = \frac{3\pi}{GT^2D}$	Oblateness Constant $q = \frac{r^3 \left(\frac{2\pi}{T}\right)^2}{GM}$
---	--	---

Where **f** = oblateness; **q** = oblateness constant; **a** = equatorial radius; **b** = polar radius; **G** = Gravitational Constant (6.67428e-11 m³/kgs²); **T** = rotational period in seconds; **D** = mean density of object; **r** = volumetric mean radius; **M** = mass of object in kilograms.

Special Note: An oblateness of 1 is **impossible**; for the object would be rotating so fast that it would have torn itself asunder long before it could achieve an oblateness of 1. One of the NCSU students in our Udava campaign (back in 1982-1997) convinced me that the maximum oblateness is 0.5. He argued (although not precisely accurate, but close enough) that the Polar Radius would be 2/3 and the Equatorial Radius would be 4/3, meaning the Equatorial Radius is twice that of the Polar Radius. It is at this point that the object would begin to tear itself apart. Thus, for the purposes of the SSG, the maximum oblateness for any celestial body would be 0.48.

Inverse Flattening Ratio

This is simply $1 \div \text{Oblateness}$. This parameter is primarily used for GIS. If you do not plan on using GIS software (such as [Quantum GIS](#), [GRASS](#), etc.), then you can skip this step.

Radii

There are three different radii for a planet: Equatorial, Polar, and Volumetric Mean. Which ones you determine is dependent upon how accurate you wish to be. All celestial bodies that rotate are actually [oblate spheroids](#). The most accurate is to compute the Equatorial and Polar Radii. For simplicity, you can just use the Volumetric Mean Radius. The CelBodCalc.exe app will also calculate these for you. Volumetric Mean Radius is simply the radius of a perfect sphere that has the same volume as the planet. If you know an oblate spheroid's volume, you can use the below equation to calculate its volumetric mean radius. The tables below generate volumetric mean radii.

$$r = \sqrt[3]{\frac{3V}{4\pi}}$$

Where **r** = volumetric mean radius; **V** = volume.

Here are the equations for equatorial radius and polar radius once volumetric mean radius and oblateness are known. However, once you use the below equations, you will have to recalculate the oblateness.

$$\begin{aligned} Er &= Vr \times (1 + f) \\ Pr &= Vr \times (1 - f) \end{aligned}$$

Where **Er** = equatorial radius; **Pr** = polar radius; **Vr** = volumetric mean radius; **f** = oblateness.

It must be remembered that an increase in a planet's mass will not mean a proportional increase in a planet's size. For example, a planet with three times the mass of Earth may only be about 1.3 times as large. Also, looking at the equation for mass ($M = DV$), you can see that size (volume) is directly proportional to mass. However, density plays a part to cause volume to increase at a smaller increment than 1:1. Below are the three forms of that equation.

$M = DV$	$D = \frac{M}{V}$	$V = \frac{M}{D}$
----------	-------------------	-------------------

For random radius, use the below table (next page). Remember, the radius generated below is volumetric mean radius. For the terrestrial planets, radius is listed in 100s of kilometers. For Jovian planets, radius is listed in 1000s of kilometers. If any die roll for radius yields a negative number; treat it as a zero (0).

Volumetric Mean Radius					
Mass	Radius	Mass	Radius	Mass	Radius
Lunan		Glacial		Terran	
0.01-0.1	16+(d10-1)	0.01-0.1	16+(d20-2)	0.5-0.75	50+(d12-1)
0.1-0.25	24+(d12-1)	0.1-0.25	33+(d20-2)	0.75-1	60+(d12-1)
		0.25-0.5	50+(d20-1)	1-1.25	70+(d12-1)
Pelagic		Oceanic		Vesuvian	
0.5-0.75	50+(d10-2)	1.5-2	86+(d20-5)	3-4.5	78+(2d8-2)
0.75-1	58+(d10-2)	2-2.5	100+(d20-4)	4.5-6	90+(2d8-2)
1-1.25	66+(d12-2)	2.5-3	115+(d20-4)	6-8	103+(2d8-2)
1.25-1.5	75+(d12-2)				
Furian		Subjovian		Jovian	
8-10	116+(d6-1)	0.03-0.1	15+(d20-4)	0.3-1	60+(d12-1)
10-12	120+(d6-1)	0.1-0.2	30+(d20-4)	1-2	70+(d12-1)
12-14	124+(d6-1)	0.2-0.3	45+(d20-4)	2-3.5	80+(d12-1)
Superjovian		Hyperjovian			
3.5-5	80+(d12-1)	8-11	95+(d12-1)		
5-6.5	85+(d12-1)	11-15	105+(d12-1)		
6.5-8	90+(d12-1)				

Mass

The masses listed in the below tables are in multiples of Jupiter or Earth. For the Jovians, they are listed in multiples of Jupiter masses. For the terrestrials, they are listed in multiples of Earth masses. To convert to kilograms, multiply the planet's mass factor by the below listed values.

Jovian Mass

Subjovian		Jovian		Superjovian		Hyperjovian	
01-09	0.03	01-09	0.3	01-10	3.5	01-07	8
10-18	0.06	10-18	0.5	11-20	4	08-14	8.5
19-27	0.09	19-27	0.7	21-30	4.5	15-20	9
28-36	0.12	28-36	0.9	31-40	5	21-27	9.5
37-45	0.15	37-45	1.1	41-50	5.5	28-34	10
46-54	0.18	46-54	1.3	51-60	6	35-40	10.5
55-63	0.21	55-63	1.5	61-70	6.5	41-47	11
64-72	0.23	64-72	2	71-80	7	48-54	11.5
73-81	0.25	73-81	2.5	81-90	7.5	55-60	12
82-90	0.27	82-90	3	91-00	8	61-66	12.5
91-00	0.3	91-00	3.5			67-73	13
						74-80	13.5
						81-86	14
						87-93	14.5
						94-00	15

Terrestrial Mass

Lunan		Glacial		Terran		Pelagic	
01-07	0.01	01-07	0.01	01-07	0.5	01-09	0.5
08-15	0.03	08-15	0.03	08-15	0.55	10-18	0.6
16-23	0.05	16-23	0.05	16-23	0.6	19-27	0.7
24-31	0.07	24-31	0.07	24-31	0.65	28-36	0.8
32-38	0.09	32-38	0.09	32-38	0.7	37-45	0.9
39-46	0.11	39-46	0.11	39-46	0.75	46-54	1
47-54	0.13	47-54	0.13	47-54	0.8	55-63	1.1
55-61	0.15	55-61	0.15	55-61	0.85	64-72	1.2
62-69	0.17	62-69	0.17	62-69	0.9	73-81	1.3
70-77	0.19	70-77	0.2	70-77	0.95	82-90	1.4
78-84	0.21	78-84	0.3	78-84	1.05	91-00	1.5
85-92	0.23	85-92	0.4	85-92	1.15		
93-00	0.25	93-00	0.5	93-00	1.25		

Terrestrial Mass

Oceanic		Vesuvian		Furian	
01-07	1.5	01-09	3	01-07	8
08-15	1.6	10-18	3.5	08-15	8.5
16-23	1.7	19-27	4	16-23	9
24-31	1.8	28-36	4.5	24-31	9.5
32-38	1.9	37-45	5	32-38	10
39-46	2	46-54	5.5	39-46	10.5
47-54	2.1	55-63	6	47-54	11
55-61	2.2	64-72	6.5	55-61	11.5
62-69	2.3	73-81	7	62-69	12
70-77	2.4	82-90	7.5	70-77	12.5
78-84	2.6	91-00	8	78-84	13
85-92	2.8			85-92	13.5
93-00	3			93-00	14

For those wishing to convert mass to kilograms: Jupiter = 1.8986e27 kilograms; Earth = 5.9736e24 kilograms

Volume

Simply, this is the cubic measure of the amount of space the object occupies. The Sphere Volume equation is simpler, but the Oblate Spheroid Volume is more accurate.

Sphere Volume $V = \frac{4\pi r^3}{3}$
Oblate Spheroid Volume $V = \frac{4\pi a^2 b}{3}$ Error Margin = $\pm 0.037\%$

Where **V** = volume; **r** = volumetric mean radius; **a** = equatorial radius; **b** = polar radius.

Surface Gravity

This is the gravitational attractive force of the planet at sea level, or mean altitude. To convert the value into cm/s², multiply by 100.

$g = \frac{GM}{r^2}$

Where **g** = surface gravity in m/s²; **G** = Gravitational Constant (6.67428e-11 m³/kgs²); **M** = mass of planet in kilograms; **r** = volumetric mean radius in meters.

Ballistic Escape Velocity

Contrary to popular belief, this is not the velocity an object needs to maintain to escape a planet's gravity well. As said on this [Wikipedia](#) page, "It is the speed needed to break free from a gravitational field without further propulsion. The term escape velocity is actually a misnomer, as the concept refers to a scalar speed which is independent of direction whereas velocity is the measurement of the rate and direction of change in position of an object. A rocket moving out of a gravity well does not actually need to attain escape velocity to do so, but could achieve the same result at walking speed with a suitable mode of propulsion and sufficient fuel. Escape velocity only applies to ballistic trajectories." Thus, the reason why I added ballistic to the term.

$Ve = \sqrt{\frac{2GM}{r}}$

Where **Ve** = escape velocity for the ballistic object in m/s²; **G** = Gravitational Constant (6.67428e-11 m³/kgs²); **M** = mass of planet in kilograms; **r** = volumetric mean radius in meters

Astronomical Albedo

Also called visual geometric albedo, this is the ratio of the body's brightness at a phase angle of zero to the brightness of a perfectly diffusing disk with the same position and apparent size. Another way of looking at this, it is the amount of sunlight reflected by the body.

Since this parameter is extremely difficult to randomize and requires quite a bit of complex math, I usually just arbitrarily choose a number between 0.42 to 0.31 $((d12 + 30) \div 100)$ for an Earth-like planet. Earth's astronomical albedo is 0.367 ([JPL Planetary Fact Sheet](#)). Just use some logical reasoning when choosing this parameter.

Albedos of typical materials in visible light range from up to 0.9 for fresh snow, to about 0.04 for charcoal, one of the darkest substances. Deeply shadowed cavities can achieve an effective albedo approaching the zero of a perfectly black body. When seen from a distance, the ocean surface has a low albedo, as do most forests, while desert areas have some of the highest albedos among landforms. Most landform areas are in an albedo range of 0.1 to 0.4. The average albedo of the Earth is about 0.37. This is far higher than for the ocean primarily because of the contribution of clouds. Thus, depending upon your world's cloud cover, you could make the +30 modifier above as low as +15, up to as high as +40.

Human activities have changed the albedo (via forest clearance and farming, for example) of various areas around the globe. However, quantification of this effect on the global scale is difficult.

Two common albedos that are used in astronomy are the (V-band) visual geometric (or astronomical) albedo (measuring brightness when illumination comes from directly behind the observer) and the Bond albedo (measuring total proportion of electromagnetic energy reflected). Their values can differ significantly, which is a common source of confusion.

Some Sample Albedos	
Surface	Typical Albedo
Fresh asphalt	0.04
Worn asphalt	0.12
Conifer forest	0.08-0.15
Deciduous forest	0.15-0.2
Bare soil	0.17
Green grass	0.25
Desert sand	0.4
New concrete	0.55
Ocean ice	0.5-0.7
Fresh snow	0.8-0.9

Bond Albedo

Also called planetary albedo, this is the fraction of incident solar radiation reflected back into space without absorption. Another way of looking at this, it is the amount of energy (object flux) reflected by the body.

As with visual geometric albedo, Earth-like planets will have a bond albedo of 0.37 to 0.26. Since this parameter, like astronomical albedo, is extremely difficult to randomize and requires some complex math, I usually just arbitrarily choose a number between 0.33 to 0.26 $((d8 + 25) \div 100)$. Earth's bond albedo is 0.306 (JPL Planetary Fact Sheet). Just use some logical reasoning when choosing this parameter.

Sol System Albedos		
Planet	Astronomical	Bond
Mercury	0.142	0.068
Venus	0.67	0.9
Earth	0.367	0.306
Mars	0.17	0.25
Jupiter	0.52	0.343
Saturn	0.47	0.342
Uranus	0.51	0.3
Neptune	0.41	0.29

As can be seen by the above table, desert planets (Mars) will have a slightly lower bond albedo and even lower astronomical albedo. Cloud covered planets like Venus will have a much higher bond albedo. Ice ball worlds (like Hoth in *Empire Strikes Back*) will have a very high visual geometric albedo and a slightly higher bond albedo, dependent upon how clean or dirty the ice is.

Object Flux

This is the total amount of energy received by the object.

$$F = \frac{L}{4\pi d^2}$$

Where **F** = amount of energy received in W/m²; **L** = luminosity of emitter in Joules; **d** = distance (mean orbital radius) from emitter in meters.

Land/Ocean Ratio

This is simply a listing of a ratio of the percentage of land to the percentage of ocean. For example, Earth's is 29/71, meaning there is 29% land to 71% ocean. You are not restricted to

listing this as land/ocean. If desired, you could list it as ocean/land. Just be consistent and annotate how you list it.

Total Surface Area

This is the total area of the planet. There are two different methods. One is for an oblate spheroid using the equatorial and polar radii. The other is for a perfect sphere. Of course, the first is the more accurate, but the second is simpler. Also remember, you can get this value using the CelBodCalc.exe app which calculates total surface area using the first equation.

Oblate Spheroid Surface Area $A = 2\pi \left(a^2 + \frac{b^2}{\sin\alpha} \ln \left(\frac{1 + \sin\alpha}{\cos\alpha} \right) \right)$ Error Margin = ±0.01371%
Sphere Surface Area $A = 4\pi r^2$

Where **A** = area; **a** = equatorial radius; **b** = polar radius; **α** = arcos(b/a); **r** = volumetric mean radius.

Land Surface Area

This is nothing more than converting the land percentage into a decimal and multiplying it by the total surface area. Most often, I never bother with listing ocean area since it is the land area (livable surface without special habitation constructs) I am more interested in.

Orbital Characteristics

Orbital Period

This is the time it takes the object to orbit the primary one full revolution. Time is in total seconds. Also see the appendix article, Creating Your Own Time Units.

$T = 2\pi \sqrt{\frac{a^3}{G(M + m)}}$
--

Where **T** = total time in seconds; **a** = mean orbital radius; **G** = Gravitational Constant (6.67428e-11 m³/kgs²); **M** = mass of central body in kilograms; **m** = mass of orbiting body in kilograms.

Orbital Eccentricity

No planet orbits a star in a perfect circle. Kepler's First Law states: "The orbit of every planet is an ellipse with the star at one of the two foci." This is the measure of the planet's orbital circularity. An eccentricity of 0 indicates a perfect circle, which is highly improbable, but not impossible. **Reason:** The constant tug-of-war of the sun, planets, and moons (if any) will have enough of an effect to prevent an orbital eccentricity of 0. Only a stellar system with a single planet could possibly have the planet's orbital eccentricity equal to 0. Unless the planet is highly eccentric, most orbits about a mature or older star will usually have an eccentricity = 0.1 to 0.01. I usually arbitrarily choose this, especially for the focus planet. If you desire randomness, use below.

Roll d100:

01; circular; $(d12 - 1) \div 10,000$.

02-66; near circular; $(2d8) \div 100$.

67-00; eccentric; $(2d20 + 20) \div 100$.

For Newborn stars, add +50. For Young stars, add +25. For all others, add +0. This depicts the orbital flux of younger stars compared to older ones. For a single planet, add -25. All these modifiers are cumulative.

If periapsis, apoapsis, and mean orbital radius are already known, orbital eccentricity may be calculated using the below equation.

$$\frac{a - p}{2r}$$

Where **a** = apoapsis; **p** = periapsis; **r** = mean orbital radius.

***Author's Note:** Before you email me and tell me that the two below parameters are actually perihelion/aphelion or perigee/apogee, read this article at [Wikipedia](https://en.wikipedia.org/wiki/Periapsis). You will see that the generic terms for these parameters is in fact periapsis/apoapsis. The -helion and -gee actually refer to the sun and Earth, respectively. But, we aren't talking about either anymore.*

Periapsis

This is the measure of the planet's closest approach to the star.

Periapsis = MOR $\times$ (1 - e); where MOR = Mean Orbital Radius, e = orbital eccentricity. Units are dependent upon units used for MOR.

Apoapsis

This is the measure of the planet's furthest excursion from the star.

Apoapsis = MOR $\times$ (1 + e); where MOR = Mean Orbital Radius, e = orbital eccentricity. Units are dependent upon units used for MOR.

Special Note: Once you calculate the periapsis and apoapsis, you will have to recalculate the orbital eccentricity.

Orbital Inclination

This is the askewment of the planet's orbital plane away from the ecliptic. In our stellar system, the ecliptic is the plane of Earth's orbit. You may use the plane of the focus planet of your stellar system as the ecliptic. Thus, for only the focus planet, its orbital inclination would be 0.0°. Otherwise, choose the inclination. If you want randomness, then see below.

Orbital Inclination:

01-95 = Ecliptical: inclination = $2d12 \div 10$; then, 01-50 = positive, 51-00 = negative.

96-00 = Eccentric: inclination = $d100$; then, 01-50 = positive, 51-00 = negative.

Orbital Obliquity

The technically accurate term for this is Obliquity to the Ecliptic. Most often called axial tilt, this is the measure of the planet's rotational axis in respect to its orbital plane. Remember, there are many factors for considering obliquity. The more upright (0° obliquity) a world is, the less seasonal changes there will be, and the smaller the regions where these changes occur. Unless the planet has a highly elliptical orbit, at 0° obliquity, there will be no seasonal changes, for the entire surface of the world will receive the same amount of energy throughout the planet's orbital period. The more sideways (90° obliquity) a world is, the more drastic the seasonal changes will be. For some parts of the world's revolution (orbital period), one pole would receive constant sunlight for half the revolution. I usually arbitrarily choose this, especially for the focus planet. If you want randomness, use below.

Roll d100:

01-20 = none; axial tilt = 0.

21-40 = small; axial tilt = $2d10$.

41-60 = moderate; axial tilt = $2d10 + 20$.

61-80 = large; axial tilt = $2d10 + 40$.

81-00 = severe; axial tilt = $4d10 + 60$.

Mean Orbital Velocity

This is the overall mean velocity the object has in its orbit about the primary. For km/s, multiply by 0.001.

$$V_o = \frac{2\pi r}{T}$$

Where **V_o** = mean orbital velocity in m/s; **r** = mean orbital radius in meters; **T** = orbital time in seconds.

Rotational Period

When first forming from the protoplanetary disk, a planet begins spinning. This is due to conservation of [momentum](#). Ever seen those ice skaters who spin faster as they pull their arms in? That is conservation of momentum. Even slowly pulling their arms inward imparts a great amount of radial inertia. Over the aeons, this spinning can be altered by major impacts and tidal tugging. If within a certain distance, tidal forces can lock the rotation of a planet so that its rotation is equal to its orbital period. In other words, one face of the planet will always face the star. A little further out, resonance between the planet and star will force a rotation that is two-thirds of its orbital period. This means the planet will rotate once every two orbital periods. Mercury has a rotational period like this. If such an orbit is elliptical enough, this can also lead to “double sunrises.” Here is an excellent video of this phenomenon by [T0R0YD @ YouTube](#). This video also shows how such a phenomenon would look like on Earth. Beyond this inner region, rotational periods become more chaotic since they are influenced by other forces besides the star’s gravitational tides. As always, you may choose the rotational period, or you may use either of the below tables for random determination. Please remember that the AU distances listed are modified by the star’s mass in Sol units.

<= 0.25 AU	Locked rotation: rotation period = orbital period.	
0.25 to 0.5 AU	Resonant Rotation: rotation period = (orbital period × (2 ÷ 3))	
>= 0.5 AU	Terrestrials roll 3d6; Jovian roll 2d6	
	2-5	2d6 hours
	6	3d6 hours
	7	4d6 hours
	8	5d6 hours
	9-10	3d6 × 2 hours
	11-12	3d6 × 3 hours
	13	3d6 × 5 hours
	14	1d6 days (= 86,400 seconds)
	15	2d6 days
	16	5d6 days
	17-18	3d6 × 5 days

Alternative Rotational Period

01-10	Very fast	2d10 ÷ 2 hours
11-30	Fast	2d10 hours
31-70	Moderate	4d10 + 2 hours
71-90	Slow	1d100 × 1d10 hours
91-00	Very slow	1d100 × 1d100 hours

Longitudinal Orbital Parameters

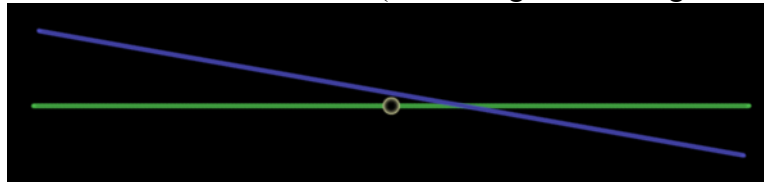
Special Notes: *Virtually none of these will ever be in the same location. The actual chance of any two of these parameters being at the same location was once calculated to be 1 in 1e24 (equivalent to rolling 12 straight "00" on a d100).*

Randomizing these parameters is not possible, for one will affect the range in which the others may be located. If you do not have a good understanding of orbital mechanics, then skip this section of parameters. Otherwise, you have to use some really brutal mathematics to calculate these parameters. Usually, I do not include these parameters, unless I want to create a .cel or .celx file for use in [Celestia](#) for the entire system.

All of these parameters are measured in degrees ranging from 0 to 359.999... Of course, this means that an arbitrary 0° direction must be chosen. As mentioned, if you do not understand orbital mechanics well enough, then just skip this. However, if you choose to create these parameters, I usually choose the 0° point as being when the planet is directly in line between the star and the galactic center at a particular point in time known as the [Epoch](#). Also, check this article at [Wikipedia](#). There are some external links. Also do a web search for “Keplerian Elements”. Just remember to visit the scientific and university sites.

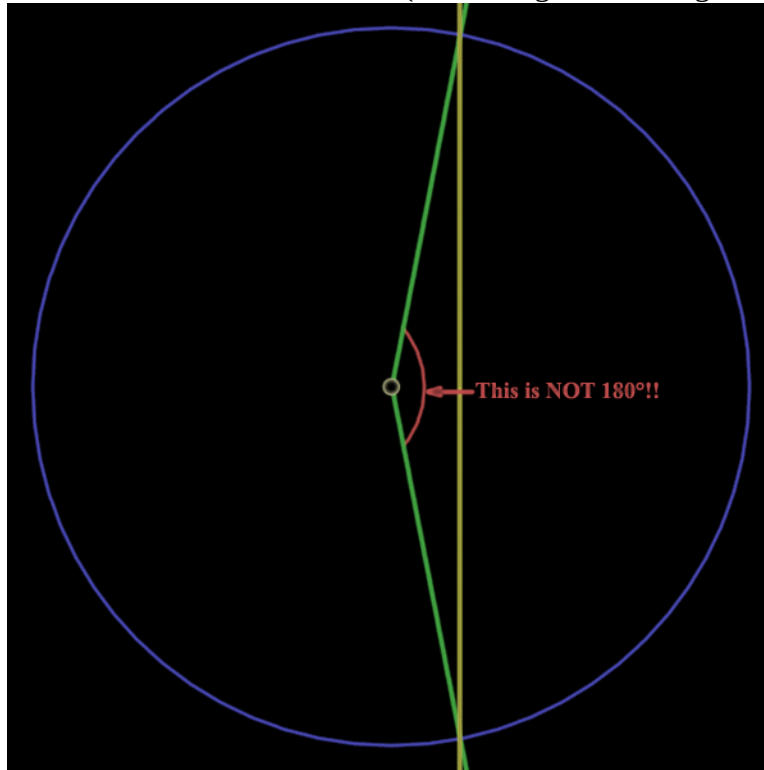
Contrary to common logic, a planet’s Ascending Node and Descending Node may not be 180° apart. The same holds true for Periapsis and Apoapsis. See images below for a visual representation for why not. The third image below gives a three dimensional visual representation. Of course, the images are exaggerated for emphasis. However, periapsis and apoapsis will be very close to 180° apart, and no greater than $\pm 2.5^\circ$ away from 180°.

Side View of a Planet’s Orbit (Ascending/Descending Nodes)



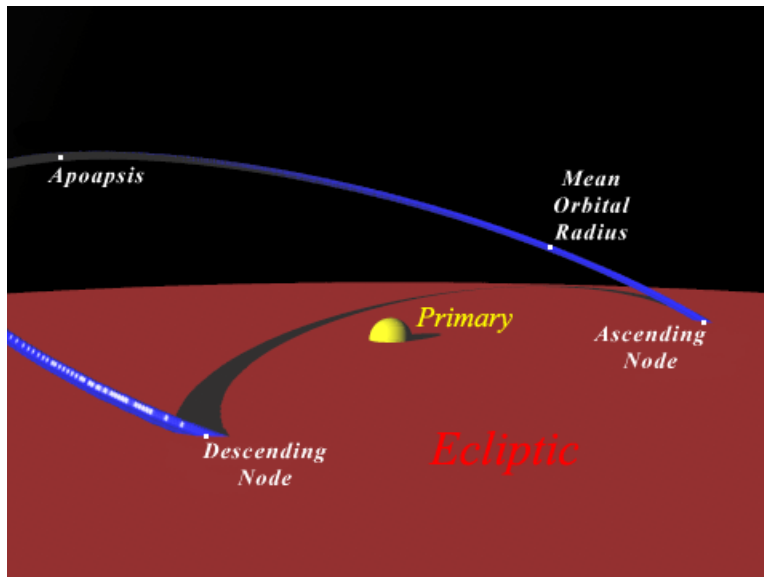
Green is the ecliptic, Blue is planet’s orbit

Obverse View of a Planet's Orbit (Ascending/Descending Nodes)



To exact same scale as above image

3-D View of a Planet's Orbit



Longitude of Ascending Node

This is the point in the planet's orbit when the planet rises above the plane of the ecliptic.

Longitude of Descending Node

This is the point in the planet's orbit when the planet sinks below the plane of the ecliptic.

Longitude of Periapsis

This is the point in the planet's orbit when the planet is at its closest approach to the star.

Longitude of Apoapsis

This is the point in the planet's orbit when the planet is at its farthest excursion from the star.

Longitude of Mean Orbital Radius

This is the point in the planet's orbit when the planet is at the mean orbital radius distance from the star. Contrary to logic, there will be only one location in the planet's orbit where this will be true. One would think it would happen twice. However, using the Earth as an example, it only happens at 100.46435°. You'd figure it would also happen at close to 280°, but it does not.

Atmospheric Characteristics

Scale Height

This is altitude above sea level, or mean altitude, by which the atmospheric pressure decreases by a factor of e ([Euler's Number](#) = 2.7182818...).

$$H = \frac{RT}{mg}$$

Where **H** = scale height in meters; **R** = Universal Gas Constant (8.3144621 J/mol K); **T** = GAST in °K; **m** = mean molecular weight in kilograms; **g** = surface gravity in m/s². Note: To get mean molecular weight in kilograms, multiply the mean molecular weight by 0.001.

Surface Pressure

For an Earth-like planet with an Earth-like atmosphere, you can calculate the mean surface pressure by converting your planet's atmosphere's mean molecular weight and surface gravity

into Earth units. Divide your planet's atmosphere's mean molecular weight by 28.96728. Divide your planet's surface gravity by 9.80665. Multiply these results together. Multiply this result by 760. The result is your planet's mean atmospheric surface pressure in mmHg.

Conversions: 1 mmHg = 1.333223684 millibars = 133.3223684 pascals = 0.1333223684 kilopascals = 0.039370079 inHg.

Surface Density

As in Surface Pressure above, except multiply by 1.225. This is the mean atmospheric surface density in kilograms/meter³.

Conversions: 1 kg/m³ = 0.062427961 lb/ft³ = 0.001 g/cm³ = 0.000578037 oz/in³.

Please Note that the above methods (pressure and density) only work for Earth-like planets with an Earth-like atmosphere.

GAST

This is the global average surface temperature (GAST) across the entirety of world's surface. It is the average of day and night temperatures also. Just because a planet has a GAST of only 284°K (11°C, 52°F) does not mean the world cannot also have some very hot temperatures. Remember, Earth's GAST is about 289°K (16°C, 61°F) and has some temperatures that hit 333°K (60°C, 140°F).

Special Note: You probably chose the planet's astronomical albedo. Just remember this, the lower it is, the higher the GAST.

$$T = \left(\frac{L(1 - A)}{16\pi\sigma D^2} \right)^{0.25}$$

Where **T** = temperature in degrees Kelvin; **L** = luminosity of emitter in W/s; **A** = object's astronomical albedo; **σ** = Stefan-Boltzmann Constant (5.6704e-8 W/m²°K⁴); **D** = mean orbital radius in meters.

Diurnal Temperature Range

Also called daily temperature range, this is the average range of diurnal temperatures the planet experiences during one rotation. Remember, this is just an average, not the extremes. For example, Earth's DTR is 283 to 293 °K (10 to 20 °C, 50 to 68°F). Also remember this is the temperature range and is not added to the GAST.

Wind Speeds

This is the range of wind speeds. The upper limit of this is the extremes that can only be experienced during violent weather such as some thunderstorms, tornadoes, and hurricanes. Earth's wind speeds are 0 to 100 meters per second (0 to 360 kph, 0 to 224 mph). Most often, the average wind speed will be one-tenth the maximum. Your best choice for an Earth-like planet is just to choose the same value (0 to 100 m/s). Then again, if you wanted to create another Arrakis, the upper limit of wind speeds could be as high as 200 m/s (720 kph, 447 mph).

Conversions: 1 m/s = 3.6 kph = 2.236936292 mph

Mean Molecular Weight

For your convenience, I have included an app which will help greatly in this step. It is named SSGCalc.exe. Explaining how to calculate mean molecular is worthy of a few pages of text and actually quite simple. However, since I have included a calculator program to do it for you, why waste the paper?

Atmospheric Composition

Use the AtmosCalc.exe app for this step. You will be able to fiddle around with the numbers in parts per million until you get what is desired.

Halogens

I have seen many persons wanting to make an exotic and corrosive atmosphere by using other natural gases such as: fluorine, chlorine, bromine, hydrofluoride, hydrocyanide, nitric oxide, ethane, fluoromethane, hydrogen sulfide, hydrogen chloride, sulfur dioxide, and/or sulfur trioxide. Only problem with these gases is that all of them are *highly* reactive with other substances, even in the absence of oxygen. In any atmosphere much like Earth's, these gases will rarely exist beyond a lifetime of a few months, perhaps a year at most, easily combining with water vapor, and thus raining out of the atmosphere to be easily broken down in the oceans and other environments. Besides, these gases will only exist in large amounts in an atmosphere of a highly volcanic planet. And if the planet is volcanic enough to have these gases in large amounts, it would hardly support any life except in the extreme (such as some bacteria and some algae).

Besides, if you truly want a corrosive atmosphere, an atmosphere like Venus will do nicely. Venus's atmosphere is composed of 96.5% Carbon Dioxide, 3.5% Nitrogen, 150ppm Sulfur Dioxide, 70ppm Argon, 20ppm Water, 17ppm Carbon Monoxide, 12 ppm Helium, trace of others. Although water is rather scarce, there is still enough to create carbonic acid, which is the prime ingredient for sodas (called [carbonated water](#)). Combined with a pressure over 90 times that of Earth and temperatures averaging around 730K (457C, 854F), this creates a very hostile environment for almost anything we can currently build. The longest lasting lander probe ([Venera 13](#)) only survived for 127 minutes. Atmospheres with some water vapor will create carbonic acid from carbon dioxide, sulfuric acid from sulfur dioxide, nitric acid from nitrous oxide, hydrochloric acid from hydrochloride, and hydrofluoric acid from hydrofluoride. Exotically corrosive enough?

Also, remember that the most reactive gas known is oxygen. Oxygen will react with every other element or substance, even the noble gases. No other element or substance is as reactive as oxygen. Although it may take quite a bit longer, oxygen will even rust stainless steel. Only gold is the least reactive substance with oxygen. But, like stainless steel, given enough time, oxygen will react and combine with even gold. Now you know why gold is considered the most precious of metals.

Chapter 5: Moons

Almost every planet has satellites of one form or another. Even in our system has 6 of the 8 planets with satellites. Even some Kuiper Belt Objects have satellites, such as [Haumea](#) and [Eris](#). There is even an asteroid with a satellite: [Ida with satellite Dactyl](#). These only suggest that objects with satellites may be the norm, instead of the exception.

Tidal Forces

Perhaps the most important effect a fairly large moon can have on a terrestrial planet is its stabilization effect of the planet's axial tilt (obliquity to the ecliptic, a.k.a. Orbital Obliquity). With a large enough moon, the moon's gravitational tidal forces can override the effects from other planets in the system. Without our Moon, Earth's axial tilt would wobble wildly from time to time. In as little as a few millennia, the tidal tugs from other planets could tilt a planet from no tilt to a tilt over onto its side, or even upside down like Venus, causing extreme seasonal changes. Such catastrophic events would not be very conducive for the development of complex life. With a stable axial tilt, complex life can develop and adapt to and take advantage of the seasonal changes (if any).

With the development of oceans and the tidal effects on those oceans, tidal pools and estuaries can form which can serve to help life make the gradual transition from marine to terrestrial life.

Tidal forces are the result of the fact that gravitational attraction drops off with distance. The nearest point of a moon will be pulled more strongly than the farther point of the moon. This has the effect of stretching the moon slightly. If the moon orbits or rotates fast enough, this stretching effect can give the moon a molten core as the forces stretch and relax the moon's shape. A very good example of this is Jupiter's moon Io. Io is the most seismically and volcanically active object in our system, even more so than our Earth. Europa is another good example as the tidal forces help heat the water under its icy crust to create surface regions of slushy ice which help to resurface Europa, erasing evidence of any impact events. Also, the thin icy crust can allow impactors to penetrate deep enough to be back-filled, and thus erased.

Tidal forces are like a double-edged sword, they cut (effect) both ways. In its ancient past, when the Moon was much closer to the Earth, its tidal force was enough to pull the land up to 80 meters higher when it was overhead. Now, the Moon is too far away to affect the rigid crust, but it does affect the liquid oceans. It is the tug of the Moon and the friction between the oceans and crust that is helping to slow the Earth's rotation. Eventually, in another billion years or so, the Earth's rotation will slow enough that the Moon will only be visible from one side of the Earth. Yes, the Earth and Moon will eventually tidally lock with each other and become a double planet system instead of its current planet-moon system.

The Roche Limit

The Roche Limit is the critical distance in which a moon may exist, or it gets torn apart forming rings. Gravitational tidal forces from the planet will simply tear apart any moon that may wander within this limit. Also, note that the Roche Limit is measured from the planet's center, not the surface. Although density is a variable, it works out to a distance equal to the planet's

radius $\times 2.446$. For example, the Roche Limit for Earth equals 15,600,833 meters; or 9,222,733 meters above the equatorial surface. Inside this limit, only rings can exist. Outside, moons. If you know the radius and density of the planet and the density of the moon, you can calculate the exact distance the moon may be before it is torn apart from the planet's gravitational tidal forces by using the below equation.

$$D = R \left(2 \frac{\rho M}{\rho m} \right)^{\frac{1}{3}}$$

Where **D** = Roche Limit; **R** = radius of primary object; **ρM** = density of primary object; **ρm** = density of secondary object.

Note: Units for Roche Limit are dependent upon units used for radius. If you use meters for radius, Roche Limit will be in meters. The units for both densities *MUST* be the same (standard = kg/m^3).

Hill Sphere, Hill Radius

Sometimes called the Hill Radius, and more rarely the Hill Limit, the Hill Sphere is the limit in which a moon may remain as a stable satellite before it is pulled away by the star into its own stable orbit about the star. Although the mathematics for determining this radius is fairly brutal, I have found a simplified equation that is still fairly accurate, depending upon orbital eccentricity. If the planet's orbital eccentricity is less than 0.05, then the below equation will have an error margin about $\pm 0.02104\%$. Greater orbital eccentricity will mean an even greater chance the moon will be pulled away to become a stable orbital path itself. Orbital eccentricities less than 0.00001 can be ignored (use the second equation).

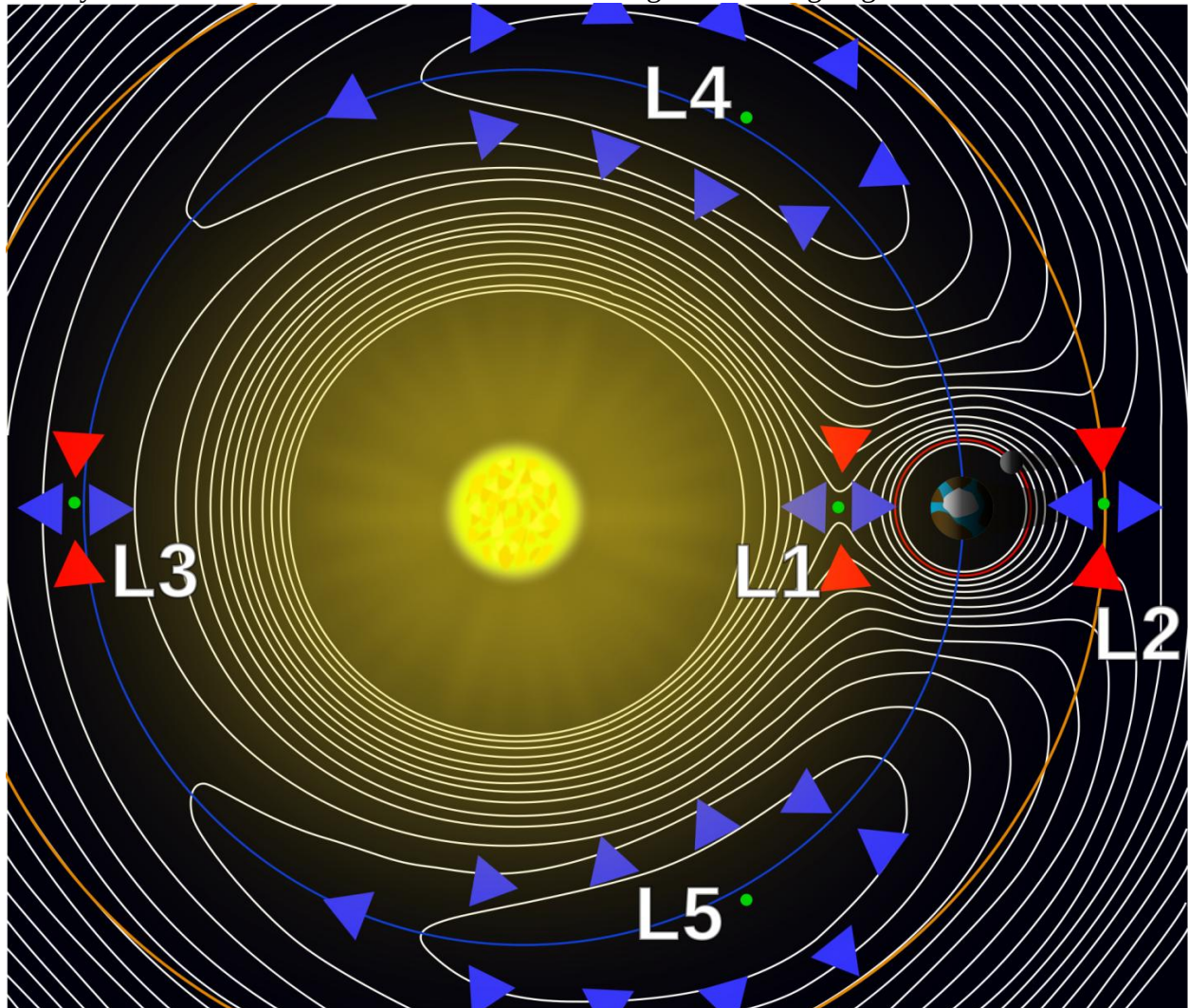
$$R = a(1 - e) \left(\sqrt[3]{\frac{m}{3M}} \right)$$

$$R = a \left(\sqrt[3]{\frac{m}{3M}} \right)$$

Where **R** = Hill Radius; **a** = mean orbital radius (planet); **e** = orbital eccentricity (planet); **m** = mass of the smaller object (planet); **M** = mass of the heavier object (star).

Notes: The unit for Hill Radius will be dependent on the unit used for the mean orbital radius (MOR). If you use kilometers for the MOR, then the Hill Radius will be in kilometers. The units for both masses *MUST* be the same (standard = kilograms).

Diagram Showing Contour Plots of the Effective Potential of a Two-Body System Due to Gravity and Inertia at One Point in Time and Showing the Five Lagrange Points and Hill Radii



In the above image, the complete circular (not necessarily true circles) contours around the planet are the safe orbits for a moon about a planet and the other ones are where another planets could safely orbit (or moon pulled away from the planet. Please note as the caption states, this is for one moment in time. The contours will vary as the planet orbits the sun due to orbital eccentricity and perturbations from the moon and other planets. Thus the above equation is only good for that single point in time. However, where eccentricities and perturbations are very miniscule, the above equation will be fairly accurate for all points of time, barring some nemesis-like event (see Nemesis Events).

Rings

Rings are related to moons and may be formed in the same processes, or formed later from a moon falling within the planet's Roche Limit. Rings lie within the Roche Limit and can extend all the way down to low orbit (maximum of one-third of Roche Limit). Rings may be complex, like Saturn's, or gossamer, like Jupiter's. Using the example for Earth above, rings may exist within 9,222,733 meters to 4,022,455 meters above Earth's equatorial surface.

Generating Moons

For planets in the Epistellar Orbits, do not bother generating moons since they cannot survive for very long. The star would pull them in and consume them within a million years, or two. As a general rule-of-thumb, the closest orbit that may have a planet that may have a satellite is 0.5 AUs (modified by multiplying the star's mass in Sol units). Another general rule-of-thumb for terrestrial type planets is the total mass of satellites cannot exceed the terrestrial planet's mass $\times 0.25$. This is the maximum for a planet-moon system. Satellites may come about for several reasons.

- Formed along with the planet in the protoplanetary disk.
- Was later captured.
- Formed due to a giant impact.
- Formed as part of a double planet and later gravitated outwards.
- Many other reasons yet to be discovered.

Moons can come from a variety of sources, and astronomers still do not completely understand what goes into the formation of planet-moon systems. It is known that most moons are most likely captured later from bits of protoplanetary flotsam. Deimos and Phobos are examples of captured moons. The Earth-Moon system is perhaps an example of the [Giant Impact Hypothesis](#).

Number of Moons

For the purposes of the SSG, it refers to moons of planetoid size or larger, ≥ 800 kilometers. Moons smaller than this are not generated by the SSG, and they are considered asteroidal. Jovian type planets can play host to literally dozens of moons, if not hundreds. This SSG only generates the major moons. If you wish to spend the time cataloguing each and every little rock that orbits a Jovian, then do so. I shall not stop you, as if I could. If you desire a tiny asteroidal moon, a ring-arc, shepherd moons, etc., then feel free to indulge yourself. Eliminating the lesser moons makes the generation of moon systems much simpler. Real world examples using this SSG are listed below.

Earth (pelagic)	1 lunan
Jupiter (Prime Jovian)	1 lunan, 2 glacial, 1 planetoid/glacial (Europa)
Saturn (cryojovian)	1 glacial, 4 planetoids
Uranus (cryosubjovian)	4 planetoids
Neptune (cryosubjovian)	1 planetoid

Terrestrial		Jovian	
01-75	1	01-25	d4
76-90	2	26-50	d6
91-98	3	51-75	d8
99	4	76-95	d10
00	5	96-00	d12

Remember, only major moons are generated.

Moon Orbits

This can be tricky. However, I have simplified it. Or, I should say that I decided to create the easiest method I could figure out. Simply roll 3d5, multiplying each roll ($d5 \times d5 \times d5$). The resulting number is the number of planet diameters the moon orbits. See the below image for a visual representation.



For Jovians, if the result is 1 or 2, then it indicates rings. For terrestrials, if the result is 1, roll d100; 01-10 = rings, otherwise reroll for orbit.

Please remember that you may choose. Again, as aforementioned, do not enslave yourself to the dice!

You can calculate the orbital period of each moon using the same equation to determine a planet's orbital period. However, the planet's mass, not the star's, is the central body. As with the planet's orbital period, the result will be in total seconds.

$$T = 2\pi \sqrt{\frac{r^3}{G(M + m)}}$$

Where **T** = total time in seconds; **r** = mean orbital radius in meters; **G** = Gravitational Constant ($6.67428 \times 10^{-11} \text{ m}^3/\text{kg s}^2$); **M** = mass of planet in kilograms; **m** = mass of moon in kilograms.

Also, if you want the moon to have a certain orbital period about the planet, you can use the below equation to calculate its orbital radius. And you could treat that moon as the Foundation Planet (Moon) for determining the other moons.

$$R = \sqrt[3]{\frac{T^2(G(M + m))}{4\pi^2}}$$

Where **R** = mean orbital radius in meters; **T** = orbital period in seconds; **G** = Gravitational Constant (6.67428e-11 m³/kgs²); **M** = mass of planet in kilograms; **m** = mass of moon in kilograms.

Types of Moons and Mass

Most often, moons will be lunan, glacial, or terran in nature. Around Jovians, the only time there will be a pelagic or oceanic type will be if the Jovian orbits the star in the Inner System orbits. Glacial type moons will only exist in the outer half of the stellar system. Occasionally, a pelagic type moon can exist due to tidal forces heating its interior. If they are in the outer half of the stellar system, these pelagics will be like Saturn's moon Titan, having oceans of methane and/or ethane instead of water. Use logical reasoning and choose the type of moon, or you can use the below table.

01-50	Planetoid Moon	0.001 to 0.01 Me
51-85	Lunan/Glacial	0.005 to 0.05 Me
86-95	Terran/Glacial	0.05 to 0.1 Me
95-00	Pelagic/Glacial	0.1 to 0.75 Me

-10 for terrestrial type planets; +10 for Jovian type planets

1 Me = 0.003 Mj and 1 Mj = 0.00095 Ms

One-Ten Thousandth Rule

This rule only applies to Jovian type planets. As a Jovian type planet forms, it begins to become massive enough that its gravity becomes very hungry, pulling in ever increasing amounts of matter. The Jovian will become hungry enough that only about 1/10,000th (0.0001) of its mass will be left for moons. I know, if you total the mass of the moons about Jupiter, Saturn, and Neptune, their total mass is more than 0.0001× that of the host planet. This is due to capture events later on. Jupiter more than likely captured Io, Europa, and Ganymede. Callisto may have formed as a moon and was later pushed outwards as the other three were captured. In all likelihood, Titan was captured by Saturn, and Triton was captured by Neptune. Uranus has far less moon mass than expected, probably due to the cataclysmic event that tilted it on its side (~98° axial tilt).

Thus, when generating moons for Jovian type planets, you need to keep this rule in mind. You may distribute this mass amongst the generated moons as desired. Or you may roll for the mass randomly using the Terrestrial Mass tables on pages 52-53. However, when all available mass is

“taken,” any remaining moons are considered to be planetoids. In Case of Emergency, when you just must have that extra luan or glacial moon, allow maximum extra 0.01 Me.

Moons of greater than the recommended maximum mass are still possible. Most of the time this will be the case since the Jovians can more easily capture moons at a later time. In such a case, you may allow an additional 1/10,000th mass for a total of 1/5000th. For Superjovians, you could allow an extra 1/10,000th mass for a total of 1/2500th. For Hyperjovians, you could allow an extra 1/10,000th mass for a total of 1/1250th.

Rings

I have simplified ring determination. If you did not get any rings in generating Moon Orbits above, then use the tables below. As always, you can just simply to choose to have rings.

01-50	No rings	01-75	Gossamer
51-00	Rings	76-00	Complex

Note: For terrestrials, add -20; for Jovians, add +20.

If desired, for ring complexity, you can simply roll d100, reading 00 as zero, to get a number 00-99. Higher numbers towards 99 would indicate more complex ring structures.

Appendices

Apparent Magnitude

This equation is only used to determine the star's magnitude when it is viewed from another stellar system, or other location. First, you will have to calculate the distance. I cannot help much with this since I have no idea where the stars are located in reference to each other. However, you can use the 3-D Pythagorean Theorem as long as you know the x, y, and z coordinates of the stars.

3-D Pythagorean Theorem

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

The zip package this document came with has an app to do this calculation for you: 3DPy. If you use light years as the units in this app, you can also calculate distance in parsecs.

Use the below equation to calculate the apparent magnitude.

$$m = M + 5 \log \left(\frac{d}{C} \right)$$

Where **m** = apparent magnitude; **M** = absolute magnitude; **d** = distance from observer; and

C = 10 if d is in parsecs

C = 32.6168807 if d is in light years

C = 206,265.325157 if d is in AUs

C = 30,857,292,643,553.7542 if d is in kilometers.

Relative Brightness Difference: This will give you relative difference in brightness between two luminous objects if the absolute or apparent magnitude is known. The magnitude must be the same type for both objects, whether apparent or absolute.

$$\Delta B = 2.512^{\Delta m}$$

Where **ΔB** = relative brightness difference; **Δm** = difference in magnitude rating; must be the same magnitude, absolute or apparent.

Angular Diameter

Ever wanted to know how big an object appears in the sky? This is called the [angular diameter](#), the angle the diameter of an object covers in the sky. To calculate this, you need to know the diameter of the object, and how far away the object is. The equation below works for any object, whether it is a star, planet, asteroid, moon, etc. Please note that the equation below is simplified and automatically converts to decimal degrees. The equation in the Wikipedia article gives the angular measure in radians.

$$\alpha = \left(\frac{D}{a}\right) \times \left(\frac{180}{\pi}\right)$$

Where α = angular diameter in decimal degrees; D = diameter of observed object; a = distance between observer and object.

Note: The units for diameter and distance must be the same.

The Wikipedia article linked above also lists some angular diameters, but it lists them in DMS (degrees, minutes, seconds). Some calculators have a DMS to DD conversion button. If you don't have one, then see below.

Converting DD to DMS

There are two methods for recording angular measure: DD (decimal degrees) and DMS (degrees, minutes, seconds).

1. Remove the number to the left of the decimal point. This is the number of degrees.
2. Multiply the remaining decimal by 60. Remove the number to the left of the decimal. This is the number of minutes.
3. Multiply the remaining decimal by 60. Leave this alone. This is the number of seconds.

Say we have an angular measure of 0.533 degrees. We have 0 degrees. Multiplying by 60 gives us 31.98 minutes. Now multiplying 0.98 by 60 gives us 58.8 seconds.

The result can be written two ways: 0d 31m 58.8s **OR** 0° 31' 58.8".

Creating Your Own Time Units

Please note that I do not go into extensive detail in this section. I write it hoping you have a general understanding of some basic math concepts.

Since you have already calculated your focus world's orbital period in total seconds, we can actually create our own time units. The simplest method is to take the total number of seconds and factor it down. The first six prime factors are: 2, 3, 5, 7, 11, and 13. You should not need a prime factor above 13. Just for comparison, an Earth Standard Year equals 31,557,600 seconds. Try and break this down into primes. You will end up with an ugly prime of 487. Nasty. But, I am not going into details about our world...

We will use the original orbital period for Onaviu for an example of what not to do. Onaviu's original orbital period was 146,313,216 seconds. It factors down to $2^{12} \times 3^6 \times 7^2$. The biggest problem with this is there is no way to make minutes and hours equal to 60 units. We need at least two 5s to do so (60 factors down to $2^2 \times 3^1 \times 5^1$). Let's see what we can do.

First, I'll try to get a minute as close as possible to 60 units. The best we can do is 56 or 64 ($2^3 \times 7 = 56$; $2^6 = 64$). Since we are talking about another world, why would they use the same kind of time units? I decided to make a minute = 56 seconds and an hour = 64 minutes.

That leaves us with $2^3 \times 3^6 \times 7^1$. Let's see if we can get 24 hours. 24 factors down to $2^3 \times 3^1$. How about that? We can make the day 24 hours.

That leaves us with $3^5 \times 7^1$. This leaves us with total days in a local year, which is 1701. Whoa! Now that is a long year! But I already knew it would since Onaviu year = 146,313,216 seconds. That is 4.636386 times longer than an Earth year. Of course you could use those remaining numbers to devise weeks and months.

However, I felt the above system would be too confusing to use in a role playing setting. Thus, I went back and totally restructured the entire stellar system to get a workable system. (I will be writing an appendix article on how to do this.) After redesigning the system, I got Onaviu's orbital period at 49,766,400. It is still longer than an Earth year, but more acceptable than previous, since it factors down to $2^{13} \times 3^5 \times 5^2$.

This allows me to make minutes and hours equal to 60 units. Thus, we have a minute = 60 seconds, and an hour = 60 minutes. I could also make a day = 24 hours. However, I already determined that Onaviu's rotational period = 115,200 seconds or 32 hours. Since 32 factors down to 2^5 , that will leave us with four 2s and three 3s.

This leaves us with $2^4 \times 3^3 = 432$. That's fine. We can use it to make a year = 432 local days. In Earth time, an Onaviu year is 576 Earth days or 1.577 Earth years.

You can create your own time units by simply determining all the prime factors of the total seconds of a length of time and combining them as desired. Just remember, when combining the factors, they are multiplied, not added.

Standards and Measures

Sol Mass	1.98892e30 kg	Gravitational Constant	6.67428e-11 m ³ /kgs ²
Sol Radius	6.955e8 m	Boltzmann Constant	1.3806504e-23 J/K
Sol Luminosity	3.839e26 J	Stefan – Boltzmann Constant	5.6704e-8 W/m ² k ⁴
Earth Standard Gravity (<i>g</i>)	980.665 cm/s ²	Light Speed (<i>c</i>)	299,792,458 m/s
Earth Standard Year	31,557,600 s	Light Year (ly)	9,460,730,472,580,800 m
Earth Standard Atmosphere	1013 mb 760 mmHg	Parsec (pc)	3.261688071 ly
Earth Mass	5.9736e24 kg	Astronomical Unit (AU)	149,597,870,691 m
Jupiter Mass	1.8986e27 kg		

Determining Orbits Using Your World as the Foundation Planet

This can seem complicated, but is actually fairly easy. Say you want a world to have a year that is 37,324,800 seconds. To find the mean orbital radius, we simply algebraically rearrange the equation for orbital period to get the below equation.

$$R = \sqrt[3]{\frac{T^2(G(M + m))}{4\pi^2}}$$

Where **R** = mean orbital radius in meters; **T** = orbital period in seconds; **G** = Gravitational Constant (6.67428e-11 m³/kgs²); **M** = mass of central body in kilograms; **m** = mass of orbiting body (your planet) in kilograms.

Convert the result R into AUs by dividing the result by 149,597,870,691. Now that you have the mean orbital radius of your world, you can treat it as the Foundation Planet. Of course, this is going to restructure your system as previously generated. But that is OK. Even if your system has a Prime Jovian, it will get readjusted along with all the other orbital paths.

For planets inside the orbit of your world, begin with the next orbit inside and divide your world's orbit value by (1.3 + (d12÷10)). Record this value and use it as the basis for the next orbit inside and repeat until you have determined the orbit values for all planets inside the orbit of your world. If any planet's orbit ends up less than the 0.02 AU orbit, then disregard and move it outside the orbit of your world, or simply delete that orbital path. Please remember the 0.02 AU orbit may be of a different value modified by the star's mass.

For planets outside the orbit of your world, begin with the next orbit outside and multiply your world's orbit value by (1.3 + (d12÷10)). Record this value and use it as the basis for the next orbit outside and repeat until you have determined the orbit values for all planets outside the orbit of your world.

Transplanetary Region

In our stellar system, we call this zone the [Kuiper Belt](#). This is a realm of pristine materials from the very beginnings of the system's formation. It lies beyond the orbit of the outermost planet and may extend another d12 + 16 AUs. It is a region mostly comprised of lumpy debris which is 50:50 rock and ice and is akin to an asteroid belt. It is from this region where most of the system's comets originate, especially the long-term comets that may take 3000 to 75,000 years to complete one orbit.

Some will only appear once on a [hyperbolic orbit](#). Although most are small, some of the objects in this region can approach large planetoid status such as [Pluto-Charon](#), [Sedna](#), [Makemake](#), and [Haumea](#), and some can approach small planet size such as [Eris](#). It is these larger transplanetary

objects that can perturb smaller objects, sending some into the inner system. The transplanetary region can contain a huge amount of material. Our Kuiper Belt is believed to contain some thirty+ Earth-masses of rock and ice. This material is very widespread and rarely forms into objects larger than 0.25 Me. If the GM desires to have a glacial planet in this region, s/he should feel free to place one there.

Even further out is the [Oort Cloud](#). This region is a hypothetical spheroidal cloud of comets which may lie up to a light year out from the star. This region is sparsely populated with small icy rocks, most being less than 200 km.

There is no table for random determination for planets, Plutoids, and planetoids for the Transplanetary Region. If you want such an object, just place it. Please note that no object will be greater than 0.25 Me. Also, its density will rarely exceed 2500 kg/m^3 , due to being mostly composed of ices.

Magnetism & Radiation

A planet's magnetic field is highly dependent upon the construction of the planet's core. Virtually all terrestrial type planets will have a nickel-iron core. Whether the core has a liquid, molten outer core and a solid inner core is the determining factor. If a planet's core has cooled to the point where it is completely solid, there will be no magnetic field generated. Or, it is very weak, too weak to protect the planet. To generate a magnetic field strong enough to protect a planet from the star's brutal emission of radiation, especially in the inner orbits zone, the outer core needs to be molten liquid metal and is dynamically convective in respect to the solid inner core.

Even if a terrestrial planet has a global magnetic field, it can fluctuate in its strength and orientation. Earth's magnetic field has exhibited several polar shifts in the past. This [geomagnetic reversal](#) was finally proven by [seafloor magnetic striping](#). It is perhaps these geomagnetic reversals that help to create the evolutionary leaps that have occurred on the Earth. This reversal occurs on a period of every 300,000 to 800,000 years. The last occurrence happened about 780,000 years ago. (Perhaps Earth is overdue for a reversal?)

A planet's [geomagnetic field](#) greatly affects the amount of radiation received on the planet's surface and the space around it. Geomagnetic fields can deflect and trap charged particles from the stellar particle winds creating highly radioactive toroidal fields about the planet like the [Van Allen Belts](#) around the Earth. These belts are very dangerous to both spacecraft and living beings without some form of shielding. However, by trapping these charged particles, the geomagnetic field keeps them away from the planet and creates a protective field so life may exist.

Jovian planets similar to Jupiter can generate incredibly powerful magnetic fields. Jupiter's is even more powerful than the magnetic field generated by a [MRI scanner](#). The frontal bow shock wave of Jupiter's magnetic field is approximately 82 Jupiter radii above Jupiter's surface (5,732,702 km). In comparison, Sol's radius is only 695,500 kilometers. The radiation belts

about Jupiter are capable of killing a human within minutes (estimated to be about 3 to 4 minutes).

Planets without protection from a geomagnetic field are virtually defenseless from the charged particle winds of their star, and the radiation level on the planet's surface will match that of the local region of space around the planet. The presence of an atmosphere can mitigate the surface radiation somewhat. However, it will not protect against [stellar flares](#) and [coronal mass ejections](#). A heavy, thick atmosphere (like Venus) can provide complete protection, generating their own magnetic field from the interaction of the atmosphere with the charged stellar particle winds, helping to prevent the atmosphere from being lost.

Planets with weak or surface-localized magnetic fields have another problem dealing with solar radiation and stellar winds. The charged particles are not stopped and bombard the atmosphere directly.

Low gravity planets ($\leq 0.35 \text{ Me}$) will have their atmosphere stripped away in a matter of a few million years to a few hundreds of millions of years. This atmosphere stripping will also ionize water into hydrogen and oxygen gases which will in turn be stripped away. This is what happened to Mars.

On heavier planets (0.4 to 1.25 Me), the charged stellar particles are absorbed by the atmosphere, again causing water to ionize into hydrogen and oxygen. Since hydrogen is so light, it is lost into space as the stellar winds strips it from the atmosphere. The oxygen will usually combine with other substances such as carbon and sulfur, forming heavier gases. The planet is able to hold onto heavier gases, creating a thick, toxic atmosphere. This is what happened to Venus.

The above two examples show the importance of a planet having a protective geomagnetic field. Without such protection, no planet could harbor complex surface life. Planetary magnetic fields (PMF) can be broken down into six groups.

PMF1: Weak, localized

This type of field is similar to those of the Moon and Mars. Basically, there is no global field. However, there may be small concentrations of polarity scattered at random across the surface.

PMF2: Weak, global

This type of field is similar to that generated by Mercury. The field strength will range between 0.01 to 0.1 gauss. This type of field can be used for compass navigation but nothing else.

PMF3: Strong, global

This type of field is similar to that generated by Earth. Its strength ranges from 0.1 to 10 gauss (Earth's field is about 0.3 gauss). This strength of field will provide excellent protection from most radiation. The only exception would be a particularly powerful [coronal mass ejection](#).

PMF4: Powerful, global

The strength of this field ranges from 10 to 100 gauss. It is very rare to see such a powerful field generated by terrestrial planets; however, it is common among the subjovian worlds. Furian terrestrial planets, and to a lesser extent, vesuvians, could generate a PMF this powerful.

PMF5: Jovian, global

Only Jovian or larger type planets could generate a PMF this powerful. The field strength ranges from 100 to 10,000 gauss. This is the most powerful PMF found. At the higher strength range, even outside the radiation belts, PMFs of this strength are dangerous to living things, and lengthy exposure can be fatal.

PMF6: Lethal

Lethal PMFs are in the 10,000+ gauss range. A magnetic field of this strength poses an immediate danger to any living thing, since the field is powerful enough to actually interfere with physical and chemical processes. This strength of field will never be found around planets, but near starspots on stellar primaries.

Magnetic fields beyond a million gauss cause atoms to be distorted into elliptical shapes, aligning along the magnetic field's lines of force. Even chemical bonds are overwhelmed and molecules will cease to exist. All matter loses its structure and becomes "magnetic soup." Fields of this strength only exist near the surface of special neutron stars called [magnetars](#). The density of a magnetar is such that a thimbleful of its substance, sometimes referred to as neutronium, would have a mass of over 100 million tons (gasp!).

- Planets of mass 0.01 to 0.1 Me are restricted to PMF1.
- Planets of mass 0.1 to 0.5 Me may be PMF1 or 2.
- Planets of mass 0.5 to 3 Me may be PMF2 or 3, depending on their rotation; less than 500 hours rotation will in almost all cases generate a PMF3 field, while slower rotation (> 500 hours) will generate a PMF2.
- Vesuvian and Furian planets may generate a PMF4 field if they rotate in less than 100 hours; otherwise they generate a PMF3.
- Subjovian planets generate a PMF4 field.
- Jovian+ planets generate a PMF5 field.

Borderline cases are naturally subject to GM's discretion.

Diagram of a Magnetosphere

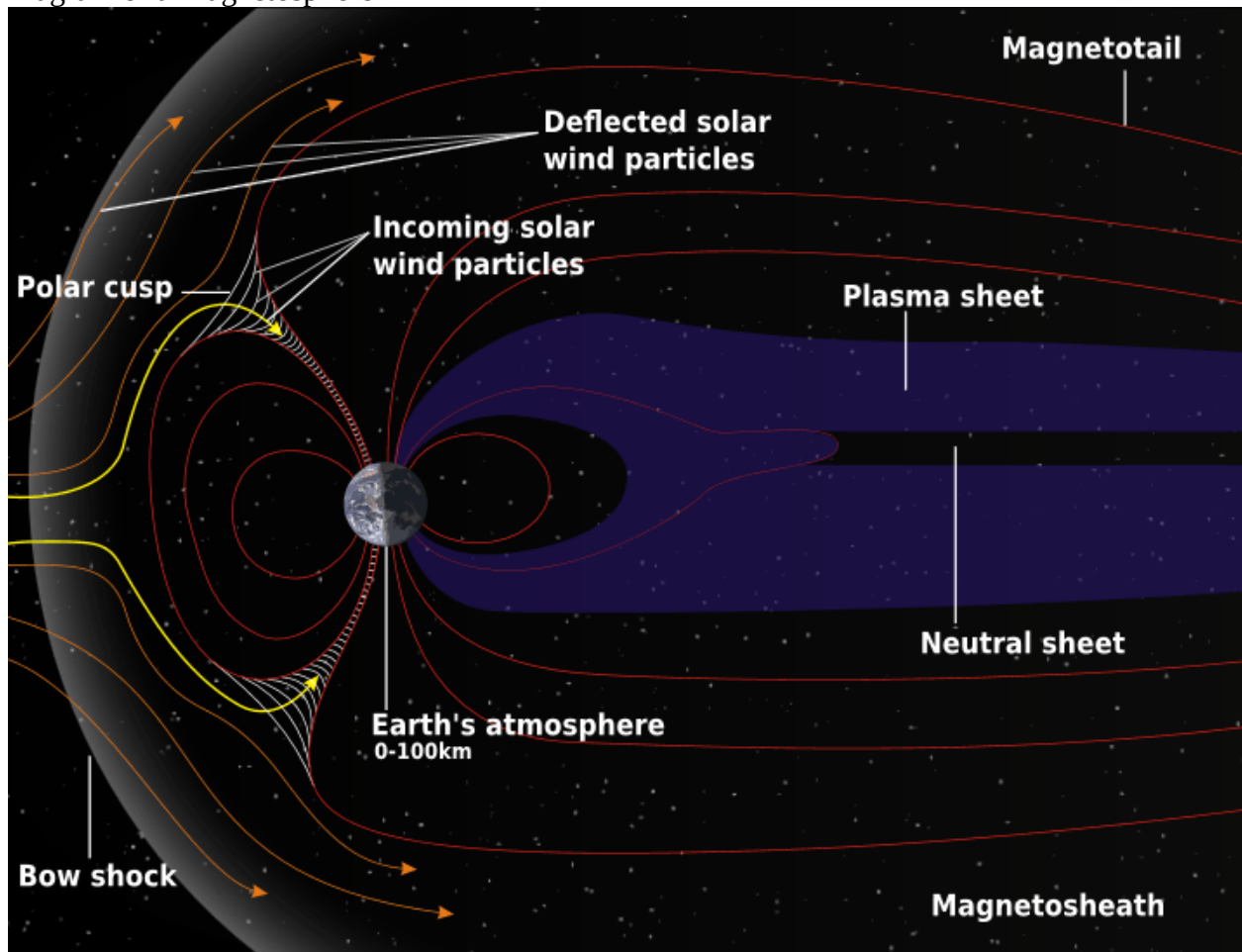
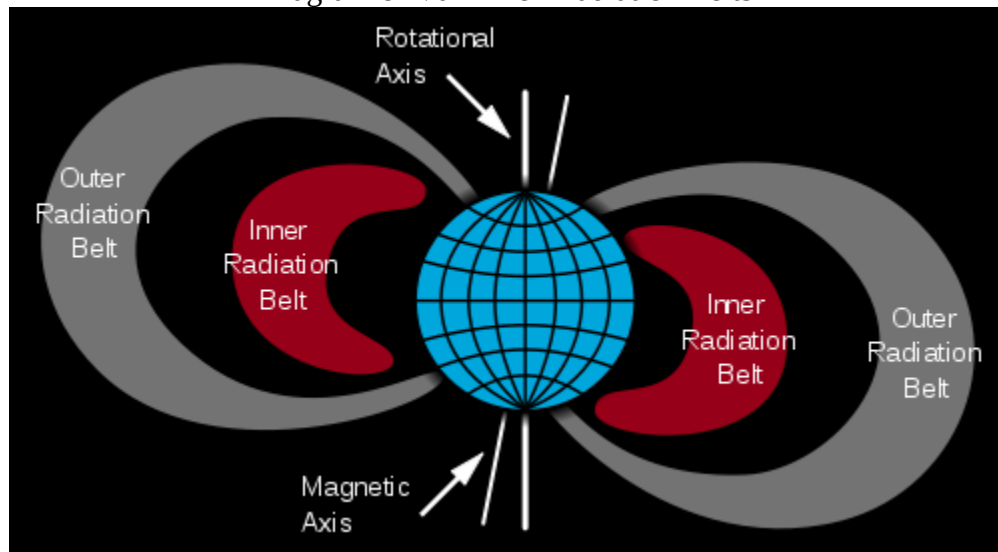


Diagram of Van Allen Radiation Belts



Geology

This is a very complex subject. I have a geology textbook that is over 1200 pages thick. And that is not including its TOC, appendices, glossary, and index. The complementary textbook on geography is over 700 pages thick. This subject is covered lightly below with a following section on the structure of an Earth-like planet (specifically Earth). For further information, do a Web search on geology, or start with this [Wikipedia](#) article. As aforementioned, be sure to visit the sites of scientific communities and universities.

All planets with solid surfaces have geology. Landform assemblages are shaped by sudden catastrophic events and slow, but inexorable, forces. There are four kinds of geology: passive, sporadic, cyclic, and active.

Passive geology is just that; passive. Planets with passive geology have either cooled enough to have lost internal heat capable of resurfacing the planet, or never had it in the first place. Landform assemblages are dominated by the remnants of past ages of activity, impact history, and weathering, if applicable. The terrain in passive geology is marked by impact craters and low, rolling mountains and hills, as well as fault cracks and cliff-like scarps. The terrain will generally be very ancient, measurable in billions of years. Mercury is a very good example of this type of geology.

Sporadic geology is very similar to passive, but in this case there is just a feeble ember still glowing at the planet's core, enough to power occasional tectonic shifts and highly sporadic volcanism. This will tend to add trace gases such as methane or sulfur dioxide to an otherwise inert atmosphere, but will have little effect on the overall terrain, which will tend to look like passive geology. Only a geologist, or an unfortunate explorer who could have sworn the volcano was extinct, would be able to tell the difference. Venus may be a good example of this form of geology.

Cyclic geology is generated by an active core that is blocked by an overly thick crust. This is often the case of low to middle-mass terrestrial planets. The geological cycle often undergoes quiescent periods for tens or even hundreds of millions of years until the trapped heat overwhelms fracture points in the crust. The situation then changes drastically, and global volcanism takes place, sometimes capable of resurfacing huge areas of the planet within a few million years, if not the entire global surface. The atmosphere often thickens and becomes highly toxic, making life very difficult for complex forms. Eventually the pressure wanes, and the surface settles into quiescence.

Active geology take place constantly, with major earthquakes and eruptions every year or so. It comes in two distinct flavors: hotspot and plate-tectonic.

[Hotspot geology](#) occurs on terran planets, as well as occasional low-mass pelagic worlds. [Mantle plumes](#) of hotter material from deep in the mantle near to the core create zones of high pressure and excessive heating under the crust. Eventually this material breaks out in a region of high volcanism. Because the crust is immobile, unlike plate-tectonic worlds, these hotspot

regions give rise to massive shield volcanoes hundreds of kilometers across, sitting on extensive highland regions. On some worlds, they can grow over a thousand kilometers across, and rise high enough to poke out of the planet's stratosphere. [Olympus Mons](#) on Mars, and the [Tharsis region](#), are very good examples of the results of hotspot geology. Also, the Hawai'i islands were formed due to both plate-tectonic and hotspot geology. Mars may now be of sporadic or passive geology. Since even sporadic geology may only be active every tens or hundreds of millions of years, we may never know.

[Plate-tectonic geology](#) is common on pelagic planets, where there is enough water to both fuel and lubricate the process. Unlike normal planetary crusts, plate-tectonic crusts are broken into a number of plates. Water from global oceans permeates the rock, lubricating it and allowing the plates to slide under each other in [subduction zones](#). This causes tension stress on the far side of the plate, and new material is dragged/pushed up from below to fill in the gap. This often forms a jagged suture line, most commonly under the oceans themselves, and thus named [mid-oceanic ridges](#). These ridges form a line of volcanic mountains often thousands of kilometers long. The subducted edges of the plates are easily melted since they carry water as an impurity, triggering volcanoes on the surface above and away from the subduction zone on the subducting plate. This complex and active process creates very young crust, often only a few tens to hundreds of millions of years old, and is dependent on large quantities of water. Continental crust lie on regions of lighter granites that are carried along like rafts, sometimes merging, sometimes being broken apart by the activity below them. Earth is a very good example of plate-tectonic geology.

Earth-like Planet Structure

Below text is borrowed from here: http://www.moorlandschool.co.uk/earth/earths_structure.htm (text has been corrected to American English).

Inner core: depth of 5,150 - 6,370 kilometers

The inner core is made of solid iron and nickel and is unattached to the mantle, suspended in the molten outer core. It is believed to have solidified as a result of pressure-freezing which occurs to most liquids under extreme pressure.

Outer core: depth of 2,890 - 5,150 kilometers

The outer core is a hot, electrically conducting liquid (mainly iron and nickel). This conductive layer combines with Earth's rotation to create a dynamo effect that maintains a system of electrical currents creating the Earth's magnetic field. It is also responsible for the subtle jerking of Earth's rotation. This layer is not as dense as pure molten iron, which indicates the presence of lighter elements. Scientists suspect that about 10% of the layer is composed of sulfur and oxygen because these elements are abundant in the cosmos and dissolve readily in molten iron.

D'' layer: depth of 2,700 - 2,890 kilometers

This layer is 200 to 300 kilometers thick. Although it is often identified as part of the lower mantle, seismic evidence suggests the D'' layer might differ chemically from the lower mantle lying above it. Scientists think that the material either dissolved in the core, or was able to sink through the mantle but not into the core because of its density.

Lower mantle: depth of 650 - 2,890 kilometers

The lower mantle is probably composed mainly of silicon, magnesium, and oxygen. It probably also contains some iron, calcium, and aluminum. Scientists make these deductions by assuming the Earth has a similar abundance and proportion of cosmic elements as found in the Sun and primitive meteorites.

Transition region: depth of 400 - 650 kilometers

The transition region or mesosphere (for middle mantle), sometimes called the fertile layer and is the source of basaltic magmas. It also contains calcium, aluminum, and garnet, which is a complex aluminum-bearing silicate mineral. This layer is dense when cold because of the garnet. It is buoyant when hot because these minerals melt easily to form basalt which can then rise through the upper layers as magma.

Upper mantle: depth of 10 - 400 kilometers

Solid fragments of the upper mantle have been found in eroded mountain belts and volcanic eruptions. Olivine ($(\text{Mg, Fe})_2\text{SiO}_4$) and pyroxene ($(\text{Mg, Fe})\text{SiO}_3$) have been found. These and other minerals are crystalline at high temperatures. Part of the upper mantle called the asthenosphere might be partially molten.

Oceanic crust: depth of 0 - 10 kilometers

The majority of the Earth's crust was made through volcanic activity. The oceanic ridge system, a 40,000 kilometer network of volcanoes, generates new oceanic crust at the rate of 17 km^3 per year, covering the ocean floor with an igneous rock called basalt. Hawai'i and Iceland are two examples of the accumulation of basalt islands.

Continental crust: depth of 0 - 75 kilometers

This is the outer part of the Earth composed essentially of crystalline rocks. These are low-density buoyant minerals dominated mostly by quartz (SiO_2) and feldspars (metal-poor silicates). The crust is the surface of the Earth. Because cold rocks deform slowly, we refer to this rigid outer shell as the lithosphere (the rocky or strong layer).

Growth of the inner core is thought to play an important role in the generation of Earth's magnetic field by dynamo action in the liquid outer core. This occurs mostly because it cannot dissolve the same amount of light elements as the outer core and therefore freezing at the inner core boundary produces a residual liquid that contains more light elements than the overlying liquid. This causes it to become buoyant and helps drive convection of the outer core. The existence of the inner core also changes the dynamic motions of liquid in the outer core as it grows and may help fix the magnetic field since it is expected to be a great deal more resistant to flow than the outer core liquid (which is expected to be turbulent).

Although the above is the structure for Earth, it can be used for other Earth-like planets.

General Diagram of Earth's Structure

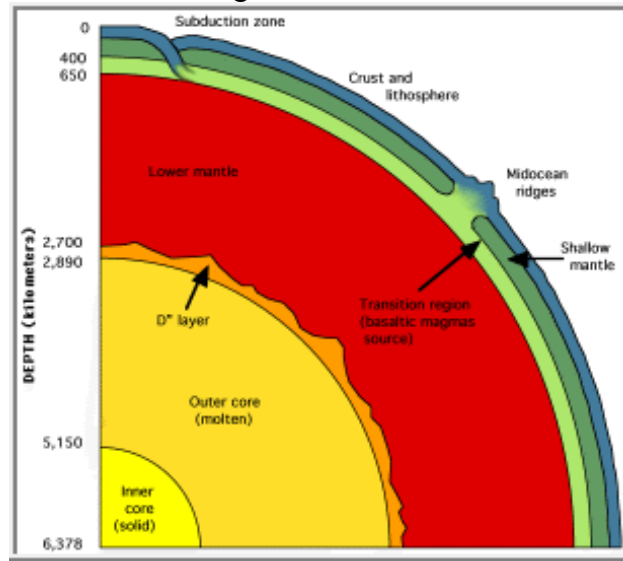
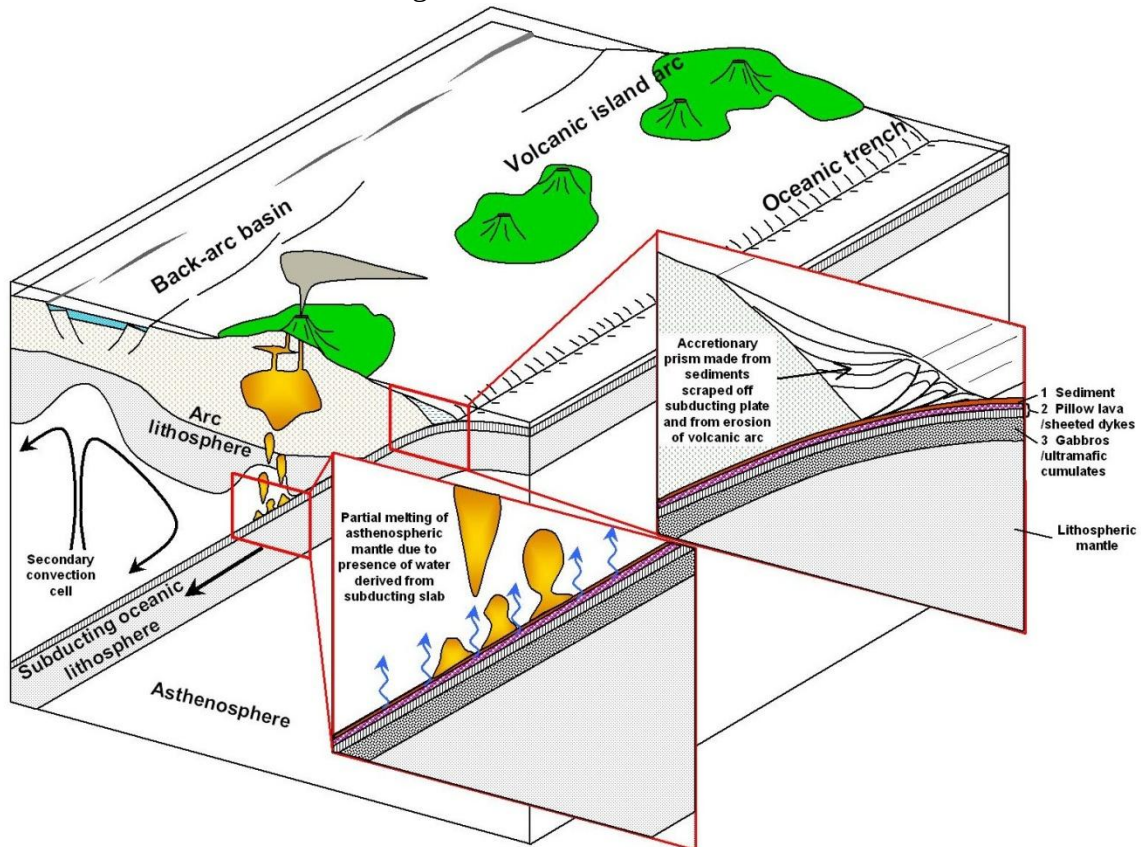


Diagram of a Subduction Zone



The Crystal Palace: [Download Wallpaper](#)



I included the above picture because it is an excellent example of some of the wondrous beauty geology can create. Read more about [The Crystal Palace](#) at National Geographic.

Oceanography

Some planets have a layer of liquid, either just below a solid, icy crust or sitting above a rocky one. These layers may range from isolated little seas to vast global oceans up to thousands of kilometers deep. Most planets have little or no surface liquid, but even they may play host to subterranean aquifers or permafrost on colder planets. Sometimes an entire ocean may be concealed below a shell of ice many kilometers thick.

Planets with seas or oceans are often the most sought after by space-faring civilizations, since it is these that have the greatest chance of supporting and harboring complex life of their own.

Composition

Most oceans in the universe are composed of water. Water is one of the most common substances in existence, and it has a broad range of temperatures and pressures at which it is liquid. Water may be quite pure, but most often carries a number of impurities. Depending on the planetary conditions, oceans may be saline, or even somewhat acidic or alkaline. Extreme concentrations of impurities are more common in smaller bodies of water. Second to water, liquid hydrocarbons like methane and ethane can sometimes form seas and oceans under

conditions of sufficient atmospheric pressure and low temperatures, but such planets are rarer than aqueous ones, and confined to the outermost half of the system.

Hydrography

Many planets have no surface water at all, but larger ones are generally wetter. Some larger planets only bear small numbers of contained seas dotted about the surface. Others can be partially or totally covered by oceans. Oceanic planets host global oceans a minimum of a hundred kilometers deep. As well as liquid oceans, planets may also develop mantles of ice near their poles, called polar caps. If you have something specific in mind, choose from the options in the below table. Otherwise, for randomness, you may consult the tables below.

Terran	Pelagic	Oceanic	Vesuvian	Furian	
01-90	01-10		01-90	Only	Exsiccated planet. There is no surface water. Permafrost or subsurface aquifers are possible on some planets.
91-00	11-30		91-00		Arid planet. Global hydrography is $\leq 20\%$ (d20). Seas are few and shallow. Most surface water is ephemeral in nature. Any permanently standing water will be exceptionally saline.
	31-60				Semi-aqueous planet. Global hydrography ranges between 21-50% (d30 + 20). There can be large bodies of water, but the planet is still dominated by deserts overall. There is usually enough water to generate some plate tectonic geology.
	61-80				Aqueous planet. Global hydrography ranges between 51-80% (d30 + 50). This type of planet is very Earth-like, dominated by oceans with isolated land masses. Plate-tectonic geology is inevitable.
	81-00	Only			Oceanic planet. Global hydrography is $\geq 90\%$ (d10 + 89). Only scattered atolls and chains of small volcanic islands exist.

-20 modifier for planets in systems dominated by Jovians in eccentric orbits.

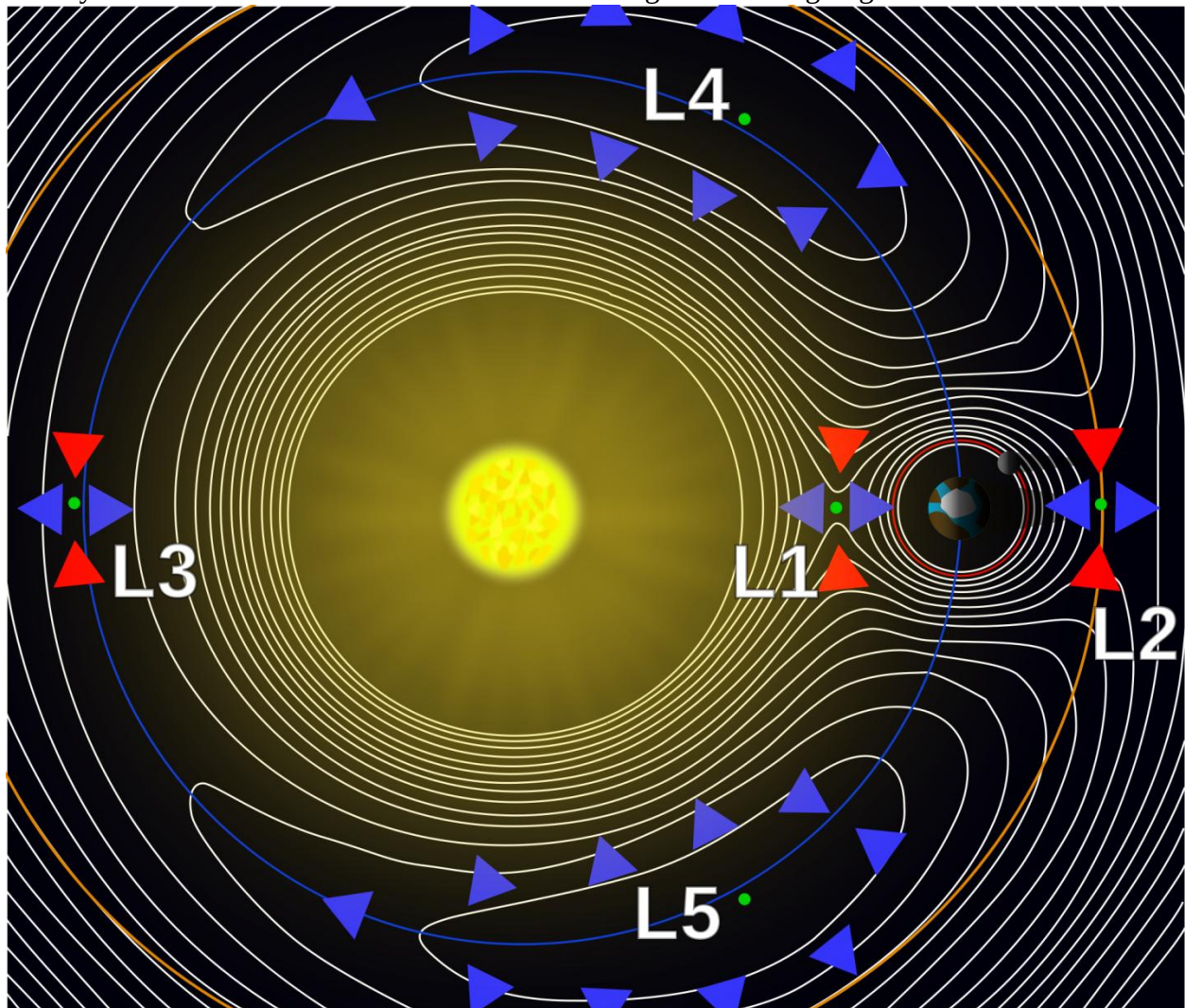
Subsurface Hydrography for Glacial Planets

01-20	Frozen planet. All water is completely frozen. Only helium can exist in liquid form.
21-60	Semi-liquid subsurface. The overlying mantle of ice contains some regions of slushy ice that is capable of flowing. The slushy ice is not truly liquid water.
61-80	Discontinuous subsurface ocean. A subsurface ocean exists in tidal stress zones (see Chapter 5: Moons) or volcanic hotspots warmed from the interior. Overall hydrography is 40-60% (d20 + 40).
81-00	Global subsurface ocean. The subsurface ocean is contiguous with little or no interruption. Overall hydrography is 70-90% (d20 + 70).

Shared Orbits

Before one can understand Shared Orbits, one must first grasp the five [Lagrange Points](#) and the [Hill Sphere](#), or Hill Radius.

Diagram Showing Contour Plots of the Effective Potential of a Two-Body System Due to Gravity and Inertia at One Point in Time and Showing the Five Lagrange Points and Hill Radii



In any orbital system involving a primary and secondary (planet and star, planet and moon, moon and planetoid, etc.), there are regions where the gravitational attractions between the two bodies cancel out and nullify each other. These points are called Lagrange points, after the mathematician who discovered them ([Joseph Louis Lagrange](#)). Of particular interest are points L4 and L5, since these are the strongest and most stable. These are located 60 degrees to either side of the planet at the same distance from the sun. Bear in mind that unless the orbit is near-circular, this does not mean quite the same thing as being ahead of and behind the planet in its orbit. Matter that falls into these areas remains stable there, and can form asteroid fields or

perhaps even planets. Jupiter plays host to the Trojan asteroids, two rich clusters of asteroids that occupy its L4 and L5 points. The mysterious object that is supposed to have hit the Earth and formed the Moon is supposed to have formed in Earth's L4 point and been driven out by perturbations from other young planets, eventually to collide with Earth. These shared orbit relationships are more stable if the central planet is at least three times heavier than any secondary planets.

Shared orbits can be used to save a planet that would otherwise be forced out by another planet's highly-elliptical orbit. GM's discretion applies here of course, but be sure not to overdo it. Remember that even Jupiter only has asteroid clusters at its L4 and L5 points, and Earth's hypothetical L4 companion, [Theia](#), became unstable and was destroyed. In nature, such shared orbits are very rare; the only known stable examples occur in two pairs of miniscule moons orbiting Saturn. Perhaps a good proportion of shared orbits are one such event per 1000 or 10,000 systems, perhaps even more rare.

It must also be remembered that the greater the mass difference between the two main bodies, the more unstable the L4 and L5 Lagrange points are as in between Sol and Earth. Also, near equal mass bodies in the next inner orbit will also tend to destabilize these points. This explains how the [Trojan Asteroids](#) can exist since there is no planet between the orbits of Mars and Jupiter to disrupt them as Venus would do to any that may have shared Earth's orbit. And it can explain why Saturn only has miniscule planetoids at its L4 and L5 points. Uranus and Neptune have no Trojans at their L4 and L5 points.

The Hill Sphere, also called the Hill Radius, basically, is a toroidal region around a planet where a satellite is safe from either falling into the planet becoming rings or being torn away by the primary into its own stable orbit. Use the below equation to calculate the Hill Radius.

$$R = a(1 - e) \sqrt[3]{\frac{m}{3M}}$$

Where **R** = Hill Radius; **a** = mean orbital radius; **e** = orbital eccentricity; **m** = mass of the smaller object; **M** = mass of the heavier object.

Notes: The unit for Hill Radius will be dependent on the unit used for the mean orbital radius (MOR). If you use kilometers for the MOR, then the Hill Radius will be in kilometers. The units for both masses *MUST* be the same.

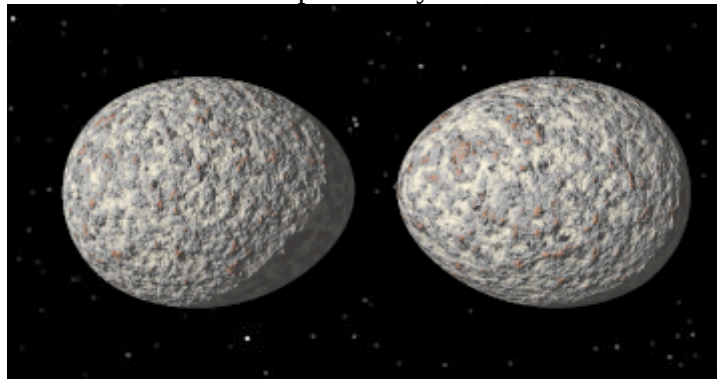
Since their first discovery, the L1 and L2 points have since been found to be unstable. An object at the L1 point would need to orbit the primary at a slower than needed rate to stay in that orbital point, and thus it would actually end up falling towards the star, further speeding it up and causing the object to leave the L1 point. An object in the L2 point would have to orbit faster than needed for that orbital point, forcing the planet into a higher orbit and causing the object to leave the L2 point. However, for a short time, a few tens to a few hundreds of millions of years, an object may orbit in the L1 and/or L2 points.

Binary Planets

For a very good example of a binary planet, read the [Rocheworld](#) series (especially the first two books: *Flight of the Dragonfly* (republished as *Rocheworld*) and *Return to Rocheworld*) written by [Dr. Robert L. Forward](#). Although written as science fiction, it is largely based on hard science fact. In my opinion, Dr. Robert L. Forward was the best hard science fiction author ever. But that is just my opinion.

Binary planets are a very rare expression of an extreme shared orbit. The two planets actually form in a binary partnership. Capture events are not possible, since any wandering planet will be moving too fast. Binary planets form within the same mass class of each other (within 10% of each other). They are also of the same density (within 5% of each other) since they are made from the same material.

A Sample Binary Planet



Because the two planets formed out of the same material in the same place, they will be very similar. Thus, rolling for one will also determine the type for the other. The only exception is that one may be completely covered by ocean while the other is a dry, arid dust-ball as in Forward's *Rocheworld* in which one was named Eau Lobe and the other named Roche Lobe.

Robert L. Forward's *Rocheworld*



Important Note: Only terrestrial planets can become binary planets. Also, the maximum size for each body of a binary planet is Oceanic. Any binary planet larger than two Oceanics will simply pull together to form a Vesuvian or Furian.

Binary planets have what may be called a double rotation. However, it is more accurate to say that the binary planet spins and rotates. Both bodies in a binary planet will spin in the same direction, *NO* exceptions. Both bodies will also rotate about each other around a common center

point, *NO* exceptions. Due to the gravitational attraction to each other, both bodies will be somewhat egg-shaped with the more pointed end towards each other. Determine spin and rotation as you would for any other planet. Spin and rotation need not be the same length of time, although they could.

Diagram Showing Spin

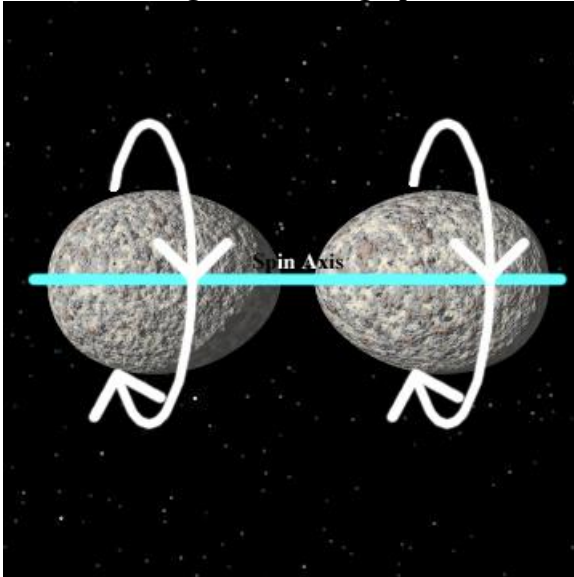
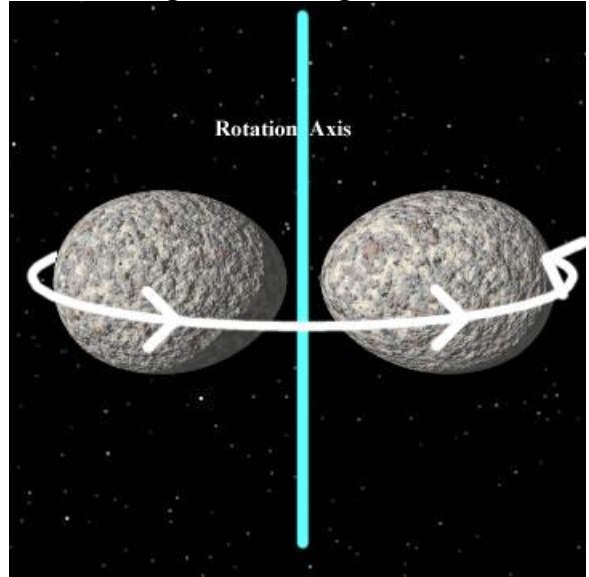


Diagram Showing Rotation



Needless to say, the combined spin and rotation will lead to some wildly varying daylight/nighttime periods. Although they will form a predictable cycle, the cycle could be as short as a few local days, or spread out over a few local years. I am afraid that you are on your own figuring this out since discussing how to determine it could involve writing a textbook.

Double Planets

The major difference between Binary Planets, Double Planets, and Planet-Moon systems is size and orbiting distance. Where a Binary Planet system has two objects literally equal to each other, a double planet can have two objects of near equal mass to two classes different. Generally, the less massive object will be within $\times 0.5$ of the mass of the more massive object. Where a Binary Planet system has two equal objects in very close proximity of each other, a Double Planet system has a greater distance apart from each other. For this SSG, a double planet is based upon the location of the barycenter of the two celestial objects. If the barycenter is located outside of both objects, then it is a double planet system (like Pluto-Charon). If the barycenter is located inside the more massive object, then it is a planet-moon system (like Earth-Moon). Also, in a Double Planet, both objects need not be of the same type. For example, you could have an Oceanic-Terran double planet. Furthermore, both objects in a double planet may or may not have tidally locked to each other, meaning they keep the same face towards each other. Usually, if the system is 6+ billion years old, the double planet will have tidally locked to each other. However, if the mass difference between the two bodies is great enough, the more massive object may not be tidally locked, but the lesser massive object will usually be tidally locked like the Earth's moon, unless the double planet system is fairly young (< 2 billion years).

Diagram of Planet-Moon Barycenter



Diagram of Double Planet Barycenter



Nemesis Events

This is named after the ancient hypothesis "[Nemesis](#)". These are events that may be caused by one of the following objects: brown dwarf, white dwarf, or neutron star. *For the purposes of this discussion, "Nemesis" refers to any massive object that can perturb the entire stellar system.* If you are into pseudo-science, Nemesis could even be a gravimetric expulsor, quantum filament, etc. The premise of this hypothesis was that there was an exceptionally difficult to detect brown dwarf, white dwarf, or neutron star that orbited the sun in a highly elliptical orbit of about 50,000 to 100,000 AUs, completing one orbit every 26 to 50 million years. The hypothesis was originally proposed as a possible explanation of the mass-extinction events on Earth every 26 to 50 million years. However, in the almost 30 years since the proposal of this hypothesis, there has been no proof discovered. Since the last mass-extinction was approximately 5 million years ago, that means if there is a Nemesis, then it should be close enough to detect (within 1 to 1.5 ly). And unbelievably as it may sound, some of our tax dollars are being used towards the attempt of detecting Nemesis. If Nemesis is a black dwarf (not possible) or a brown dwarf, it would be nearly impossible to detect it. Personally, I think the Nemesis hypothesis is just that; a hypothesis. However, if you wish to have something like a brown dwarf, white dwarf, or neutron star that is a Nemesis for your system, then put it there. You will just have to calculate

its orbital period. Just remember, even if the Nemesis has passed through the transplanetary region, it could get halfway back from its periapsis to its apoapsis before any objects from this region actually threaten the inner planets of the system. Also, unless there is an exceptionally sophisticated detection system, such threats may not be detected until it is too late to do anything about it.

Nemesis events can literally be anything that can cause a cataclysmic event. It could be something as simple as perturbing comets from the Oort Cloud and/or Kuiper Belt into the inner system. It could be something as cataclysmic as perturbing the focus planet out of its orbit caused by the Nemesis falling through the system from a highly elliptical orbit, such as passing through from above or below the ecliptic. Or, even the worst case; the Nemesis could collide with the focus planet, or pass close enough that the focus planet is completely disrupted due to the Nemesis passing within its Roche Limit of the planet. Nemesis could pass close enough to perturb the focus planet's moon into the planet. How about the even longer term effect of perturbing the system's Prime Jovian into the inner system?

I could continue, but I think your imagination is good enough. Just think about it.

Prime Jovians

Since we have been discovering systems with Prime Jovians are rarer than first thought, I felt this subject needed some further discussion. Just for a real world example, the table below shows the effect of a Prime Jovian (Jupiter) on our system. This table only focuses on the main eight planets of our system, basically comparing Jupiter to the other seven.

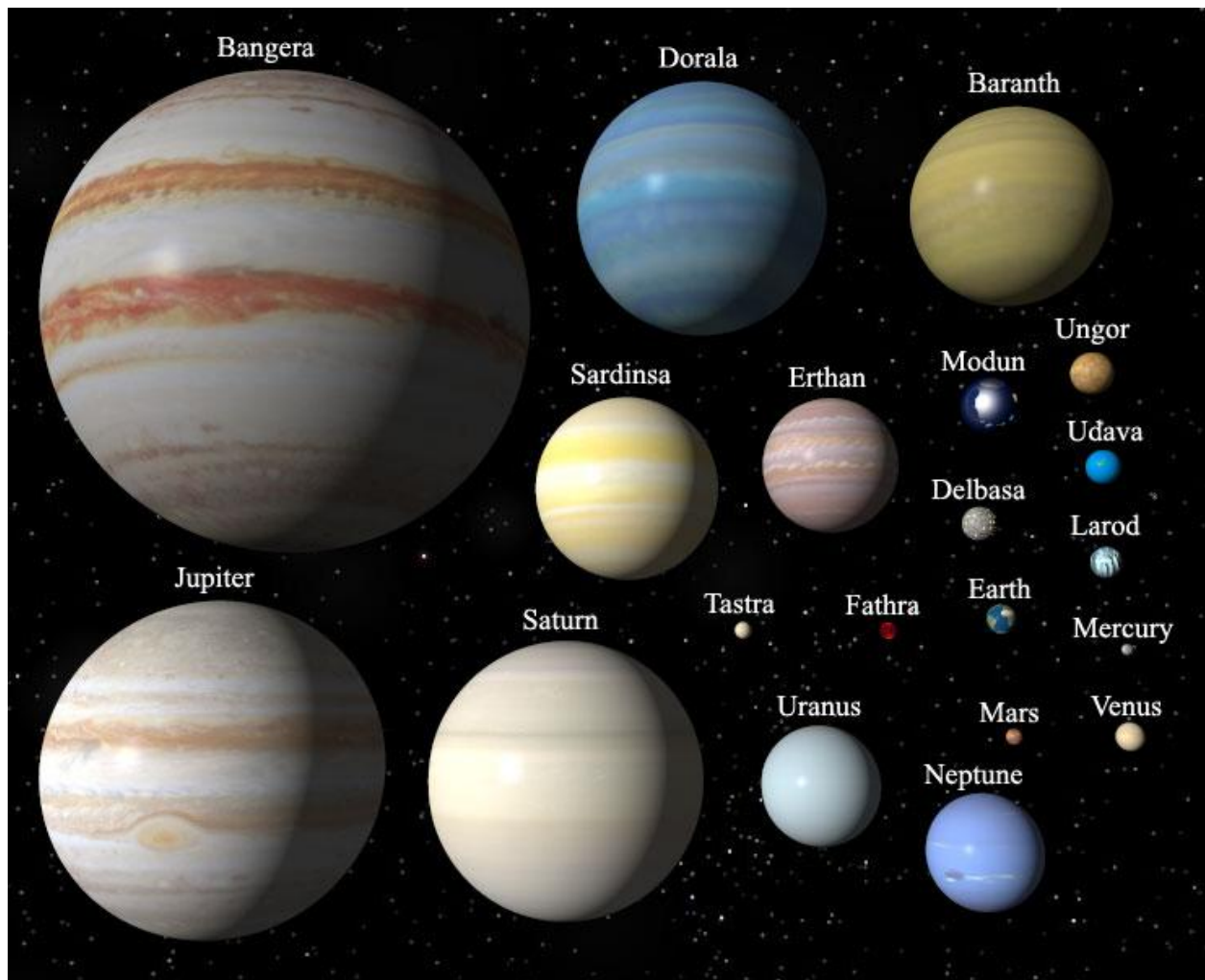
Planet	Mass	Volume
Mercury	3.302e23	6.083e10
Venus	4.8685e24	9.2843e11
Earth	5.9736e24	1.08321e12
Mars	6.4185e23	1.6318e11
Saturn	5.6846e26	8.2713e14
Uranus	8.6832e25	6.833e13
Neptune	1.0243e26	6.254e13
Total	7.6953615e26	9.6023565e14
Jupiter	1.8986e27	1.43128e15

Note: The above data was retrieved from [JPL's Planetary Data Sheets](#) site.

As can be seen, Jupiter out-masses ($\times 2.4672$) and out-sizes ($\times 1.49055$) all other planets combined. Including the planets from an old campaign (Udava) ran by my wife and me, below is an image showing the size comparisons of all these planets. As unbelievable as it may seem, the planet Bangera actually out-masses and out-sizes all other 18 planets in the image. In fact, Bangera was a borderline Brown Dwarf-Hyperjovian planet. And this system was generated from the second revision of the first SSG I wrote way back in 1983.

I even used this image as an example of how actual 3-D objects would make poor symbols in a cartography class. In fact, 1-D objects are the most perceptible when seeing size change. 2-D objects are little harder to visually see a size change. However, 3-D objects are the most difficult in perceptualizing a size change. As said, although it may not seem so, Bangera actually has a volume almost 2.1 times the volume (almost 2.4 times the mass) of all other 18 objects combined. Because of our perception, we tend to see the 2-D part of the objects (the diameter) and add that together. Our eyes do not truly perceive a three dimensional size increase. Our eyes more readily see a 2-D size increase instead. Furthermore, our eyes will more readily see a 1-D size increase than seeing a 2-D size increase. Something to remember when symbolizing your maps.

In case you are wondering, **yes**, all objects in the below image are true to scale in the 3-D. Even if you were to only look at the objects in our stellar system, Jupiter, Saturn, Uranus, Neptune, Mercury, Venus, Earth, and Mars, would you believe that Jupiter has almost 1.5 times the volume of all other seven planets in our stellar system **combined**?



This leads me to think that if we never had a Jupiter, how many other planets our system might have contained. Makes one wonder... If Saturn had been the Prime Jovian, we might have had a

planet where the asteroids are now and perhaps another terrestrial type planet between it and Saturn. We shall never know...

Now that I think about it, I ought to go back and see if Bangera was actually fusing deuterium and may have been a Brown Dwarf. I think it would be neat to have Udava orbit Bangera as a moon. With Bangera actually fusing deuterium, it would add some warmth to Udava, making it a more viable planet for life further from the stellar primary. Hmm...

Although I could run wild with my figurations of imagiments, I still tend to stick to *feasibly possible* instead of making off the wall *pseudo-science* within my stellar systems. However, I may still add some pseudo-science elements such as my ManaStorms, ManaConvulsions, ManaSurges, and ManaEruptions, but I still tried me damned best to describe them within our current understanding of physics.

Star Data Record Sheet

Star Name	
Galaxy Type	
Stellar Age Category	
System Type	
Companion 1	
Companion 2	
Prime Jovian	Yes No
Spectral Class	
Spectral Level	
Luminosity Class	
Surface Temperature	
Luminosity	
Absolute Magnitude	
Radius	
Mass	
Volume	
Mean Density	
Description	
Orbital Paths	
Inner Biosphere Radius	
Outer Biosphere Radius	
Eccentricities	
System Resources	
Star Lifetime	
Star Age	

Planetary Data Record Sheet

Name	
Orbit	
Type	
Mean Density	
Mass	
Volume	
Mean Radii – Polar	
Equatorial	
Volumetric	
Circumferences – Polar	
Equatorial	
Volumetric	
Oblateness	
Inverse Flattening Ratio	
Surface Gravity	
Ballistic Escape Velocity	
Satellites	
Rings	
Astronomical Albedo	
Bond Albedo	
Object Flux	
Magnetism	
Radiation	
Geology	
Oceanography	
Land/Ocean Ratio	
Total Surface Area	
Land Surface Area	
Mean Orbital Radius	

Permission granted to photocopy as needed for personal use.

Orbital Period – seconds	
Earth days	
Local days	
Earth years	
Orbital Eccentricity	
Periapsis	
Apoapsis	
Orbital Inclination	
Orbital Obliquity	
Mean Orbital Velocity	
Rotational Period – seconds	
Earth days	
Longitude of Ascending Node	
Longitude of Descending Node	
Longitude of Periapsis	
Longitude of Apoapsis	
Longitude of Mean Orb Rad	
Atmospheric Scale Height	
Surface Pressure	
Surface Density	
Global Average Surface Temp	
Diurnal Temp Range	
Wind Speeds	
Mean Molecular Weight	

Atmospheric Composition

Nitrogen	
Oxygen	
Argon	
Carbon Dioxide	
Neon	
Helium	
Methane	
Krypton	
Hydrogen	
Nitrous Oxide	
Carbon Monoxide	
Xenon	
Ozone	
Nitrogen Dioxide	
Iodine	
Ammonia	